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Testing and Analysis of Fasteners

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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. These bolts will be tested by using biaxial loading. The result & conclusion was drawn after the experimental testing.

Keywords: Bi-axial Loading, Fasteners, Bolt Loosening, Residual Torque, Fastener Overloading

I. INTRODUCTION

Bolted joints are one of the most common elements in construction and machine design. They consist of fasteners that capture and join other parts, and are secured with the mating of screw threads.

There are two main types of bolted joint designs: tension joints and shear joints.

In the tension joint, the bolt and clamped components of the joint are designed to transfer an applied tension load through the joint by way of the clamped components by the design of a proper balance of joint and bolt stiffness. The joint should be designed such that the clamp load is never overcome by the external tension forces acting to separate the joint. If the external tension forces overcome the clamp load (bolt preload) the clamped joint components will separate, allowing relative motion of the components.

The second type of bolted joint transfers the applied load in shear of the bolt shank and relies on the shear strength of the bolt. Tension loads on such a joint are only incidental. A preload is still applied but consideration of joint flexibility is not as critical as in the case where loads are transmitted through the joint in tension. Other such shear joints do not employ a preload on the bolt as they are designed to allow rotation of the joint about the bolt, but use other methods of maintaining bolt/joint integrity. Joints that allow rotation include clevis linkages, and rely on a locking mechanism (like lock washers, thread adhesives, and lock nuts).

Proper joint design and bolt preload provides useful properties:

1) For cyclic tension loads, the fastener is not subjected to the full amplitude of the load; as a result, the fastener's fatigue life is increased or if the material exhibits an endurance limit its life extends indefinitely. As long as the external tension loads on a joint do not exceed the clamp load, the fastener is not subjected to motion that would loosen it, obviating the need for locking mechanisms. (Questionable under Vibration Inputs.)
2) For the shear joint, a proper clamping force on the joint components prevents relative motion of those components and the fretting wear of those that could result in the development of fatigue cracks.

In both the tension and shear joint design cases, some level of tension preload in the bolt and resulting compression preload in the clamped components is essential to the joint integrity. The preload target can be achieved by a variety of methods: applying a measured torque to the bolt, measuring bolt extension, heating to expand the bolt then turning the nut down, torqueing the bolt to the yield point, testing ultrasonically, or by applying a certain number of degrees of relative rotation of the threaded components. Each method has a range of uncertainties associated with it, some of which are very substantial

Typically, a bolt is tensioned (preloaded) by the application of a torque to either the bolt head or the nut. The applied torque causes the bolt to "climb" the thread causing a tensioning of the bolt and an equivalent compression in the components being fastened by the bolt. The preload developed in a bolt is due to the applied torque and is a function of the bolt diameter, the geometry of the threads, and the coefficients of friction that exist in the threads and under the torqued bolt head or nut. The stiffness of the components clamped by the bolt has no relation to the preload that is developed by the torque.

The relative stiffness of the bolt and the clamped joint components do, however, determine the fraction of the external tension load that the bolt will carry and that in turn determines preload needed to prevent joint separation and by that means to reduce the range of stress the bolt experiences as the tension load is repeatedly applied. This determines the durability of the bolt when subjected to repeated tension loads. Maintaining a sufficient joint preload also prevents relative slippage of the joint components that would produce fretting wear that could result in a fatigue failure of those parts.

The clamp load, also called preload of a fastener, is created when a torque is applied, and so develops a tensile preload that is generally a substantial percentage of the fastener's proof strength. Fasteners are manufactured to various standards that define, among other things, their strength. Torque charts are available to specify the required torque for a given fastener based on its property class (fineness of manufacture and fit) and grade (tensile strength).

When a fastener is torqued, a tension preload develops in the bolt and an equal compressive preload develops in the parts being fastened. This can be modelled as a spring-like assembly that has some assumed distribution of compressive strain in the clamped joint components. When an external tension load is applied, it relieves the compressive strains induced by the preload in the clamped components, hence the preload acting on the compressed joint components provides the external tension load with a path (through the joint) other than through the bolt. In a well-designed joint, perhaps 80-90% of the externally applied tension load will pass through the joint and the remainder through the bolt. This reduces the fatigue loading of the bolt.

When the fastened parts are less stiff than the fastener (those that use soft, compressed gaskets for example), this model breaks down and the fastener is subjected to a tension load that is the sum of the tension preload and the external tension load.

In some applications, joints are designed so that the fastener eventually fails before more expensive components. In this case, replacing an existing fastener with a higher strength fastener can result in equipment damage. Thus, it is generally good practice to replace old fasteners with new fasteners of the same grade.

A bolted joint must maintain a minimum clamping force in order to resist loosening. The resulting fictional forces between the surfaces of the bolt, nut, and mating materials must be greater than any tangential surface forces that might act to oppose them. In order to do this, a complex set of design parameters involving the characteristics of the bolt, nut, and mating materials must be arranged such that the resistance to loosening is optimized. At the present time, what is known about how a bolt and nut interact under vibrational load is based on theoretical models and some experimental data. The following literature review is directed toward what is currently known about bolt loosening as well as the mechanics of threaded fasteners.

II. PROBLEM STATEMENT

In order to predict bolt loosening, it is important to first identify the parameters that contribute to bolt loosening so they can be quantified. The desire to identify the primary parameters that contribute to bolt loosening was the impetus for this study.

III.OBJECTIVE

The work presented in this report is directed toward a long-range goal of prediction of bolt loosening.

Once the main parameters that contribute to bolt loosening are identified, they can be quantified and, an empirical solution can be developed to predict bolt loosening.

The major emphasis of the work presented here in is the identification of the main parameters contributing to bolt loosening and to identify their relative importance and degree of contribution to bolt loosening.

IV.SCOPE

The entire range of all parameters contributing to bolt loosening could not be explored in this experiment. The parameters which affect the bolt loosening will be investigated in an experimental testing program employing a Taguchi Method design of experiment.

V. METHODOLOGY

1) *Step 1:-* We started the work of this project with literature survey. We gathered many research papers which are relevant to this topic. After going through these papers, we learnt about Bolt Loosening.
2) *Step2:-* After that the components which are required for our project are decided.
3) *Step 3:-* After deciding the components, the 3 D Model and drafting will be done with the help of CATIA software.
4) *Step 4:-* The experimental observations will be taken.
5) *Step 5:-* The result & conclusion will be drawn.

VI. COMPONENTS USED

A. Pneumatic Cylinder

Pneumatic cylinder(s) (sometimes known as air cylinders) are mechanical devices which use the power of compressed gas to produce a force in a reciprocating linear motion.

Like hydraulic cylinders, something forces a piston to move in the desired direction. The piston is a disc or cylinder, and the piston rod transfers the force it develops to the object to be moved. Engineers sometimes prefer to use pneumatics because they are quieter, cleaner, and do not require large amounts of space for fluid storage.

Because the operating fluid is a gas, leakage from a pneumatic cylinder will not drip out and contaminate the surroundings, making pneumatics more desirable where cleanliness is a requirement. For example, in the mechanical puppets of the Disney Tiki Room, pneumatics are used to prevent fluid from dripping onto people below the puppets.

Fig.1 Pneumatic Cylinder

B. Solenoid Valve

Solenoid valves are devices that use a solenoid to control valve activation. They are considered electromechanical control devices used to control liquid or gas flow. An electrical current runs through a coil to control the valve by moving a plunger. When the solenoid receives an electrical signal (energized), it channels the air supply directly to the plunger. When the electrical signal is removed (de-energized) the valve returns to its normal condition.

Solenoid valves are used in a wide variety of industries. They are used in machinery, devices, and equipment such as refrigerators and automatic faucets. Solenoid valves are commonly used in central heating systems to control the thermostat to regulate the flow of heated water to the heating element. They are also used in automatic irrigation sprinkler systems, air control, fluid control, and in pharmacology experiments.

Fig.2 Solenoid valve

C. Bolts

A bolt is a form of threaded fastener with an external male thread. Bolts are closely related to screws.

The distinction between a bolt and a screw is commonly misunderstood. There are several practical differences, but most have some degree of overlap between bolts and screws.

Bolts are for the assembly of two unthreaded components, with the aid of a nut. Screws in contrast are used in components which contain their own thread, and the screw may even cut its own internal thread into them. Many threaded fasteners can be described as either screws or bolts, depending on how they are used.

Bolts are often used to make a bolted joint. This is a combination of the nut applying an axial clamping force and also the shank of the bolt acting as a dowel, pinning the joint against sideways shear forces. For this reason, many bolts have a plain unthreaded shank (called the grip length) as this makes for a better, stronger dowel. The presence of the unthreaded shank has often been given as characteristic of bolts vs. screws, but this is incidental to its use, rather than defining.

The unthreaded grip length should be chosen carefully, to be around the same length as the thickness of the material and washers through which the bolt passes. An overly long unthreaded length prevents the nut from being tightened down correctly. An insufficient unthreaded length results in the threads extending into the hole, and places the dowel shear load onto the threads, which may cause fretting wear on the hole. No more than two turns of the thread should be within the hole.

Where a fastener forms its own thread in the component being fastened, it is called a screw. This is most obviously so when the thread is tapered (i.e. traditional wood screws), precluding the use of a nut, or when a sheet metal screw or other thread-forming screw is used.

Head designs that overlap both are the Allen or Torx heads; hexagonal or splined sockets. These modern designs span a large range of sizes and can carry a considerable torque.

D. Arduino

Arduino is an open-source hardware and software company, project and user community that designs and manufactures single-board microcontrollers and microcontroller kits for building digital devices and interactive objects that can sense and control both physically and digitally. Its products are licensed under the GNU Lesser General Public License (LGPL) or the GNU General Public License (GPL), permitting the manufacture of Arduino boards and software distribution by anyone. Arduino boards are available commercially in preassembled form or as do-it-yourself (DIY) kits.

Arduino board designs use a variety of microprocessors and controllers. The boards are equipped with sets of digital and analog input/output (I/O) pins that may be interfaced to various expansion boards or breadboards (shields) and other circuits. The boards feature serial communications interfaces, including Universal Serial Bus (USB) on some models, which are also used for loading programs from personal computers. The microcontrollers are typically programmed using a dialect of features from the programming languages C and C++. In addition to using traditional compiler toolchains, the Arduino project provides an integrated development environment (IDE) based on the Processing language project.

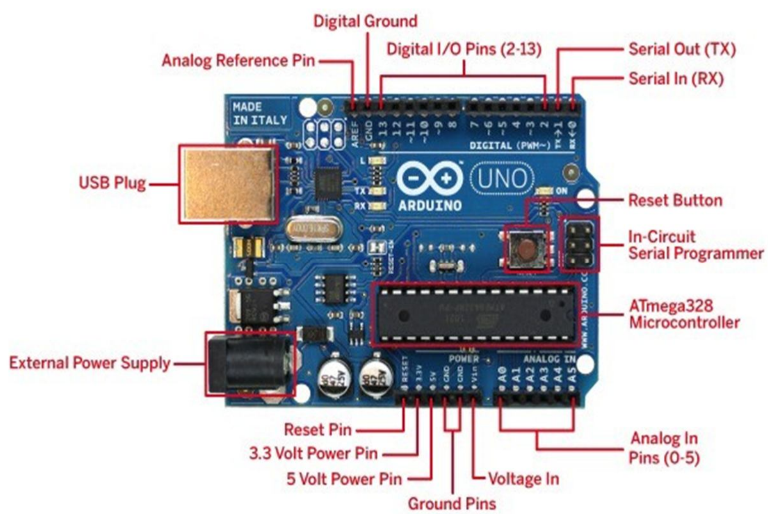

Fig.3: ARDUINO: Parts and Components

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The Arduino project was started at the Interaction Design Institute Ivrea (IDII) in Ivrea, Italy. At that time, the students used a BASIC Stamp microcontroller at a cost of $50, a considerable expense for many students. In 2003 Hernando Barragán created the development platform wiring as a Master's thesis project at IDII, under the supervision of Massimo Banzi and Casey Reas. Casey Reas is known for co-creating, with Ben Fry, the Processing development platform. The project goal was to create simple, low cost tools for creating digital projects by non-engineers. The Wiring platform consisted of a printed circuit board (PCB) with an ATmega168 microcontroller, an IDE based on Processing and library functions to easily program the microcontroller. In 2003, Massimo Banzi, with David Mellis, another IDII student, and David Cuartielles, added support for the cheaper ATmega8 microcontroller to Wiring. But instead of continuing the work on Wiring, they forked the project and renamed it Arduino.

The initial Arduino core team consisted of Massimo Banzi, David Cuartielles, Tom Igoe, Gianluca Martino, and David Mellis, but Barragán was not invited to participate.

Although the hardware and software designs are freely available under copyleft licenses, the developers have requested the name Arduino to be exclusive to the official product and not be used for derived works without permission. The official policy document on use of the Arduino name emphasizes that the project is open to incorporating work by others into the official product. Several Arduino-compatible products commercially released have avoided the project name by using various names ending in -duino.

E. Relay

A relay is an electrically operated switch. Many relays use an electromagnet to mechanically operate a switch, but other operating principles are also used, such as solid-state relays. Relays are used where it is necessary to control a circuit by a separate low-power signal, or where several circuits must be controlled by one signal. The first relays were used in long distance telegraph circuits as amplifiers: they repeated the signal coming in from one circuit and re-transmitted it on another circuit. Relays were used extensively in telephone exchanges and early computers to perform logical operations.

A type of relay that can handle the high power required to directly control an electric motor or other loads is called a contactor. Solid-state relays control power circuits with no moving parts, instead using a semiconductor device to perform switching. Relays with calibrated operating characteristics and sometimes multiple operating coils are used to protect electrical circuits from overload or faults; in modern electric power systems these functions are performed by digital instruments still called "protective relays". Magnetic latching relays require one pulse of coil power to move their contacts in one direction, and another, redirected pulse to move them back. Repeated pulses from the same input have no effect. Magnetic latching relays are useful in applications where interrupted power should not affect the circuits that the relay is controlling.

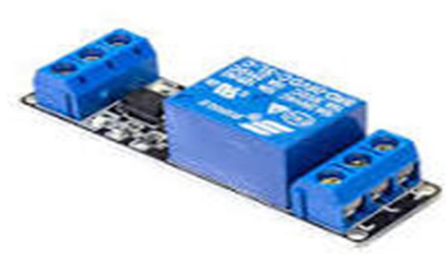

Fig. 4: Relay Module

VII. VIBRATION AND ITS TYPES

Vibration is a mechanical phenomenon whereby oscillations occur about an equilibrium point. The word comes from Latin vibratio ("shaking, brandishing"). The oscillations may be periodic, such as the motion of a pendulum—or random, such as the movement of a tire on a gravel road. Vibration can be desirable: for example, the motion of a tuning fork, the reed in a woodwind instrument or harmonica, a mobile phone, or the cone of a loudspeaker. In many cases, however, vibration is undesirable, wasting energy and creating unwanted sound. For example, the vibrational motions of engines, electric motors, or any mechanical device in operation are typically unwanted. Such vibrations could be caused by imbalances in the rotating parts, uneven friction, or the meshing of gear teeth. Careful designs usually minimize unwanted vibrations.

The studies of sound and vibration are closely related. Sound, or pressure waves, are generated by vibrating structures (e.g. vocal cords); these pressure waves can also induce the vibration of structures (e.g. ear drum). Hence, attempts to reduce noise are often related to issues of vibration.

A. Types of Vibration

1) Free vibration occurs when a mechanical system is set in motion with an initial input and allowed to vibrate freely. Examples of this type of vibration are pulling a child back on a swing and letting it go, or hitting a tuning fork and letting it ring. The mechanical system vibrates at one or more of its natural frequencies and damps down to motionlessness.

Fig. 5: Types of Vibration Vs Displacement

2) Forced vibration is when a time-varying disturbance (load, displacement or velocity) is applied to a mechanical system. The disturbance can be a periodic and steady-state input, a transient input, or a random input. The periodic input can be a harmonic or a non-harmonic disturbance. Examples of these types of vibration include a washing machine shaking due to an imbalance, transportation vibration caused by an engine or uneven road, or the vibration of a building during an earthquake. For linear systems, the frequency of the steady-state vibration response resulting from the application of a periodic, harmonic input is equal to the frequency of the applied force or motion, with the response magnitude being dependent on the actual mechanical system.
3) Damped vibration when the energy of a vibrating system is gradually dissipated by friction and other resistances, the vibrations are said to be damped. The vibrations gradually reduce or change in frequency or intensity or cease and the system rests in its equilibrium position. An example of this type of vibration is the vehicular suspension dampened by the shock absorber.

VIII. DESIGN AND TESTING

A. Vibration Testing

Vibration testing is accomplished by introducing a forcing function into a structure, usually with some type of shaker. Alternately, a DUT (device under test) is attached to the "table" of a shaker. Vibration testing is performed to examine the response of a device under test (DUT) to a defined vibration environment. The measured response may be fatigue life, resonant frequencies or squeak and rattle sound output (NVH). Squeak and rattle testing is performed with a special type of quiet shaker that produces very low sound levels while under operation.

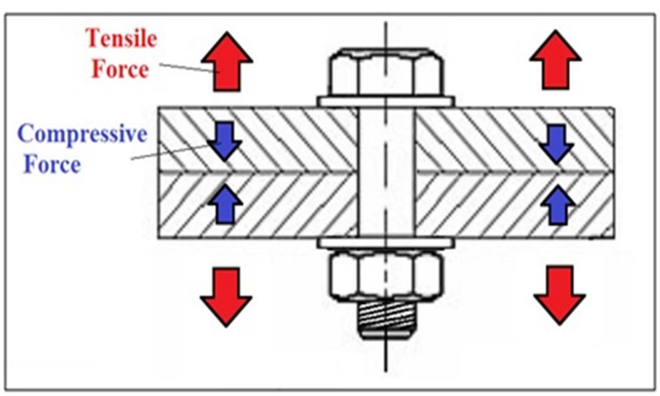

Fig. 6: Forces in Nut-Bolt Assembly

For relatively low frequency forcing, servo hydraulic (electrohydraulic) shakers are used. For higher frequencies, electrodynamic shakers are used. Generally, one or more "input" or "control" points located on the DUT-side of a fixture is kept at a specified acceleration.[1] Other "response" points experience maximum vibration level (resonance) or minimum vibration level (anti-resonance). It is often desirable to achieve anti-resonance to keep a system from becoming too noisy, or to reduce strain on certain parts due to vibration modes caused by specific vibration frequencies.

The most common types of vibration testing services conducted by vibration test labs are Sinusoidal and Random. Sine (one-frequency-at-a-time) tests are performed to survey the structural response of the device under test (DUT). A random (all frequencies at once) test is generally considered to more closely replicate a real world environment, such as road inputs to a moving automobile.

Most vibration testing is conducted in a 'single DUT axis' at a time, even though most real-world vibration occurs in various axes simultaneously. MIL-STD-810G, released in late 2008, Test Method 527, calls for multiple exciter testing. The vibration test fixture used to attach the DUT to the shaker table must be designed for the frequency range of the vibration test spectrum. Generally for smaller fixtures and lower frequency ranges, the designer targets a fixture design that is free of resonances in the test frequency range. This becomes more difficult as the DUT gets larger and as the test frequency increases. In these cases multi-point control strategies can mitigate some of the resonances that may be present in the future. Devices specifically designed to trace or record vibrations are called vibroscopes.

B. Biaxial Testing

Biaxial tensile test is a tensile testing in which the sample is stretched in two distinct directions. This technique is used to obtain the mechanical characteristics of anisotropic materials, such as composite materials, textiles, and soft biological tissues. There are three main types of biaxial tensile testing:

1) Bursting test, based on a circular specimen clamped along the edge and inflated by air or water under pressure until the specimen bursts;
2) Cylinder test, based on a hollow cylinder subjected to internal pressure and axial pressure or tension;
3) Plane biaxial test which offers the best result because of the independent force introduction in the two main directions.

One of the key aspects is the sample mounting, which should consider the initial gauge length, the correct positioning of the fabric into the clamps and the correct application of the strain transducers in the central area.

The next crucial stage is load application. This issue has been widely investigated but there is no loading path universally adopted by the testing laboratories. It has to be said that the loading cycles mainly depend on the scope of the test and it is unrealistic to consider the possibility of elaborating a single loading path able to fulfil at the same time all the requirements imposed by the investigation of the initial behaviour, the service behaviour, the behaviour at breaking load and long term behaviour. This part of the procedure should provide a valid approach to the establishment of a load profile, describing the effects of the parameters involved, in order to fully investigate the material response according to the required repeatability. Since coated fabrics do not follow an elastic behaviour, once the stress is removed the sample maintains a certain level of permanent strain, a plastic deformation. This behaviour is known as residual strain and is present both in monoaxial and biaxial tests. The main value of residual strain is shown between the first and second load cycle, decreasing to zero after a number of cycles that depends on the material properties, the applied load and the time for which it has been applied. This is due to the creep of the yarns and the coating material and to the internal frictional effects. In order to obtain a realistic description of the material the strain should be measured within a unique load cycle, assuming equal to zero the strain at pre-stress. For this reason the loading cycle considered for the strain measure is generally preceded by identical cycles in a number sufficient to stabilise the sample response. In order to remove the residual strain previous researches considered adequate the application of five identical loading and unloading cycles, the TensiNet design guide consider three or five repetitions to be sufficient, depending on the testing protocol. While the Membrane Structures Association of Japan prescribes the repetition of the cycles three times, but only for the 1:1 load ratio which separates the others. This offers several advantages in the comparison of readings carried out within the same test and with other tests.

For the investigation of the typical behaviour of an in-situ fabric, it is proposed a test protocol divided into: pre-stress, conditioning and a final radial test regime. The pre stress was considered fundamental in order to reproduce the typical stress state of a membrane structure after the initial pre-tensioning is concluded, it is held for a certain amount of hours and generally set at 1.3% UTS for PVC/polyester fabric and 2.5% UTS for PTFE/glass fibre fabric.

A second issue which should be taken into account is the effect of the load history on the response of the fabric. This may have important consequences for the structure of the load profile, which may turn out be inadequate for the investigation of in-situ conditions of fabrics which have not yet undergone the maximum stress state applied during conditioning.

Thirdly, it is crucial to determine the possible effects of the recent load history on the fabric response, in particular whether the load sequence followed by approaching a particular stress state result in a different level of strain. The effects due to the level of minimum pre-stress, load history and the recent load history should be carefully considered when developing the testing load regime. The aim is to assure the repeatability of the test and that the data obtained are in accordance with the scope of the test.

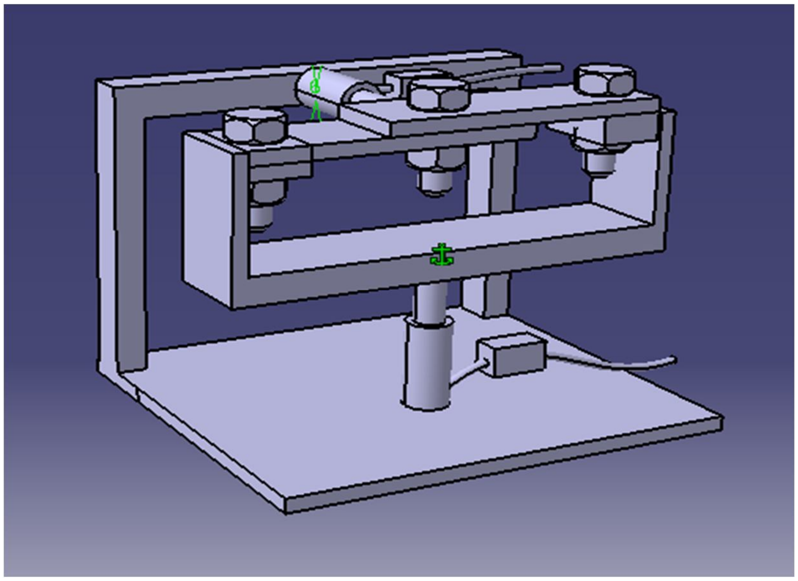

Fig. 7: Catia Model of Bi-axial Testing

IX. CALCULATIONS

A. Pneumatic Cylinder

1) Given data

2) Selecting Cylinder: 25*25

Volume of air exhaust = stroke *area of piston
= 25*π/4*25^2
= 12271.83 m^3

Area of piston =π/4*25^2 = 490.873 mm^2

Outstroke force (F) = pressure *Area of cylinder
= 0.4*490.873
= 196.349 N

Piston rod area A1 = π/4*d^2
= π/4*8^2
= 50.20 mm^2

Effective area = piston area- piston rod area
= 490.873 -50.20
= 440.673 mm^2

In-stroke force = P*A
=0.4*440.673
=176.2692 N

X. FUTURE SCOPE

The entire range of all parameters contributing to bolt loosening could not be explored in this experiment. The parameters which affect the bolt loosening will be investigated in an experimental testing program employing a Taguchi Method design of experiment.

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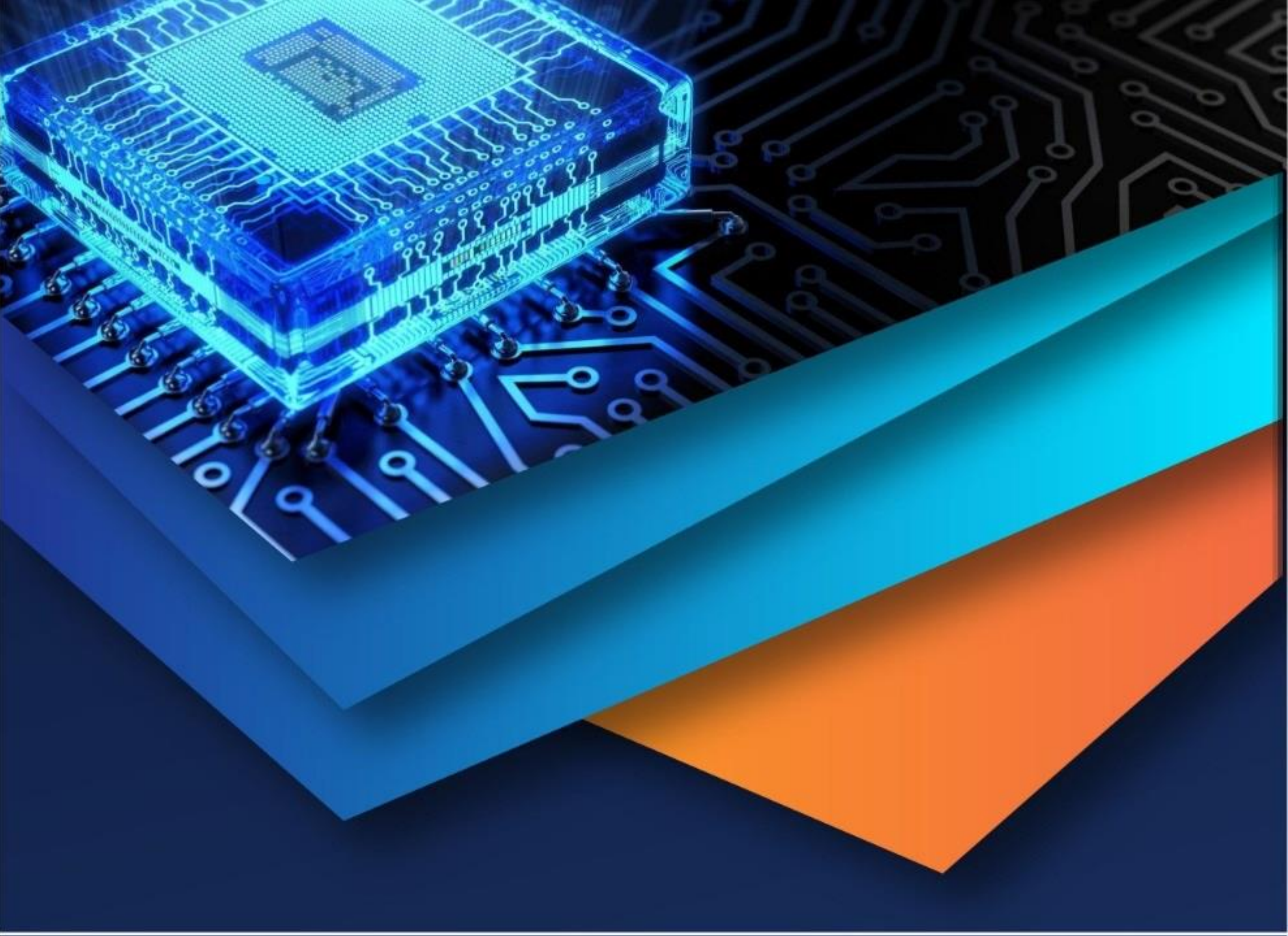

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