# "Study of Vibration Loosening of Bolted Joints- A Review"

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**Abstract:** In the present research paper a detailed review on root causes and reasons which results in vibration loosening of bolted joints and fasteners has been carried out. Authors have reviewed the various research studies carried out by previous researchers in this particular area of research. Main reasons of loosening are vibrations incurred, cyclic loading and unloading of threaded nut-bolt assembly components. Many researchers have developed machine set ups for their experimental work. Loosening i.e. unlocking rotation of bolted assembly is mainly caused by the restoring action of an elastic torsion of a bolt shank because of the relative motion relative to its mating surface on threads.

After review of literature it was concluded in this review that the most occurring root cause of loosening is side sliding of the nut or bolt head relative to the fastened joint, resulting in the relative motion occurring within the threads. If this does not occur or can be prevented, then the loosening of bolts can be reduced.

**Key Words:** Bolt, Bolted Joints, Vibration, Loosening of bolts.

## 1. INTRODUCTION

Nuts and bolts were invented as early as the old civilization. During times of roman civilization the Romans used them to bind windows, secure and tight chariots and build simple machines. In as early as the 1350-1450 AD Leonard Deviance and Luc Bassoon had designs of bolts. The earliest nuts- bolts had square heads nowadays these are hexagonally shaped. The first generations of bolts were handmade [39].

A fastener is an Engineering component or device that mechanically joins or affixes two or more objects together. In General, for applying semi permanent joint between any two parts Bolted joints are used. There are two parts in the assembly A) Nut and other is B) Bolt.

Bolt, can be described as a type of fastener characterized by a helical ridge, known as an external thread or just thread, which are wrapped around a cylinder. Some screw threads are designed to mate with a complementary thread, known as an internal thread, often in the form of a nut or an object that has the internal thread formed into it. Other screw threads are designed to cut a helical groove in a softer material as the screw is inserted. The most common uses of these fasteners are to hold objects together and to position objects. Where, a nut can be described as a type of fastener with a threaded hole. Nuts are always used opposite a mating bolt to fasten a pair of parts together. These two parts are kept together by combination of their threads' friction, a slight stretch of the bolt, and compression of the parts.[44]
The bolted joints are essential and critical elements of a machine component or a structural assembly. The main purpose of the bolted joint is to transfer loads among various members of the structural assembly. There is a necessity to optimize the design of a bolted joint, which will maximize the load carrying capacity, structural integrity and minimize weight factor of the whole machine or structure. The mechanical joints are widely used in various bolted assemblies and this makes their design to be of great importance for both cost reduction by saving in weight, as well as for the prevention of failure.

The bolted joints are classified in to two categories depending on the direction of the external load acting on a joint. When the forces on the bolted join are acting parallel to the axis of bolt, the joint is said to be loaded in tensile and is called tensile joint. Tensile joint is the most commonly used joint in the structures. When the forces on the joint are acting perpendicular to the axis of the bolt, the joint is called shear joint [1].

In many Engineering applications where vibration or rotation may work a nut loose, various locking mechanisms may be employed: such as lock nuts, adhesives, safety pins, lock wire, nylon inserts, or slightly oval-shaped threads. The most common shape is hexagonal, for similar reasons as the bolt head - six sides impart a good granularity of angles for a tool to approach from, but more corners would be vulnerable to being rounded off. Other specialized shapes exist for certain needs, such as wing nuts for finger adjustment and captive nuts for inaccessible areas.

Bolted joints are usually made up of the bolt group which includes head, stud, and nut and the flange top and bottom. Bolted connections are designed to hold two or more parts together to form an assembly. Because of various loading conditions, especially at high loads, bolted connections can loose and separate. To minimize this bad effect, a pretension is applied to the bolt. This will insure that the connection will not get separated, provided the applied load remains less than the pretension. There is one another component which is inserted between the nut and a bolt is a Washer. A washer is a component in the form of a thin disc shaped plate with a hole in the centre that is normally used to distribute the load of a threaded fastener, such as a screw or nut. Other uses are as a spacer, spring, wear pad, preload indicating device, locking device, and to reduce vibration rubber washer. Washers usually have an outer diameter about twice the width of their inner diameter.

Washers are usually metal or plastic. High quality bolted joints require hardened steel washers to prevent the loss of pre-load due to the applied torque.Washers and gaskets are usually designed for different functions and made differently. Washers are also important for preventing galvanic corrosion, particularly by insulating steel screws from aluminum surfaces.

Washers can be classified into three types;
1) Plain washers, which evenly spread applied load, and prevent any damage to the surface being fixed, or provide electrical insulation;
2) Spring washers, which have axial movement flexibility and are used to prevent fastening loosening due to shocks and vibrations; and,
3) Lock washers which prevent fasteners loosening by preventing unscrewing rotation of any fastening device; locking washers are generally also spring washers.

In most Engineering applications, the lead of a screw thread is so chosen which will impart adequate friction to prevent linear motion being converted to rotary that is so the screw does not slip even when linear force is applied so long as no external rotational force is present. This characteristic is vital in the majority of applications. A screw thread, which is commonly shortened to thread, is a helical structure used to convert between rotational and linear movement and force. A screw thread is a ridge wrapped around a cylinder or cone in the form of a helix, with the former being called a straight thread and the latter called a tapered thread. A screw thread is the essential feature of the screw as a simple machine and also as a fastener. More screw threads are produced each year than any other machine element. By far the most occurring root cause of loosening is side sliding of the nut or bolt head relative to the fastened joint, resulting in the relative motion occurring within the threads. If this does not occur or can be prevented, then the bolts will not loosen, even if the joint is subjected to severe vibration. Hence more research is going on in this area to prevent loosening of bolted joints because of vibrations.

## 2. LITERATURE REVIEW

By the study of engineering literature it is believed that vibration is the main cause which results in loosening of bolts. Vibration occurs in most of the structures, machines and almost all the dynamic systems resulting in many unwanted situations. Vibration results in undesired motions, undesirable noise and unwanted dynamic stresses which results in fatigue and consequent failure of the structure/machine, undesirable power and energy losses, reduced reliability, under rated performance and resulting loosening of bolts in treaded joints[43]. Self loosening of threaded fasteners leads to a reduction and sometimes the increase of this pre load which is frequently leads to joint failure [41].

The first study on threaded fastener loosening done by Goodier and Sweeney [2] in 1945 who proposed that in the course of dynamic loading and unloading, initial loosening is caused by loading on the assembled components and tightening caused by unloading, the net effect being a small rotation in the nut but that is not completely true.

Junker [3] developed a test and showed that the transverse joint movement can cause loosening; he concluded that transverse vibrations have more adverse effects than axial vibrations.

Kenny and Patterson [4] modified the nut thread form for reducing the stress concentration which occurs during cyclic loading and had described a technique for determining the load distribution experimentally. Gerbert [5] have analyzed different designs of bolted joints, which are externally loaded. The stiffness of bolt predicted in this study was higher than the bolt load. In his research load application factor was introduced in VDI 2230 and a new fraction was determined, which was much lower than the existing one. But in practical design, there was no effect of the location of the external load on this application factor, but this was affected by the layout of the bolted joint.

Ramey and Jenkins [6] did their study on the Structural Test Division of MSFC. The objective of their study was to identify the main design parameters contributing to the loosening of bolts due to vibration and to identify their relative importance and degree of contribution to bolt loosening. Vibration testing was conducted on a shake table with a controlled-random input. Test specimens which contained one test bolt were vibrated for a fixed amount of time and a percentage of pre-load loss was measured. Each specimen tested implemented some combination of eleven design parameters as dictated by the design of experiment methodology employed.

The design parameters were: bolt size, lubrication on bolt, whole tolerance, initial pre-load, nut locking device, grip length, thread pitch, lubrication between mating materials, class of fit, joint configuration, and mass of configuration. These parameters were chosen for this experiment because they are believed to be the design parameters having the greatest impact on bolt loosening. The results of the investigation indicated that nut locking devices, joint configuration, fastener size, and mass of configuration were significant in bolt loosening due to vibration. The results of this test can be utilized for future research the complex problem of bolt loosening due to vibration.

Ireman [8] has developed a three-dimensional finite element model for composite joint to determine non-uniform distribution of stress through the thickness of composite laminate near the bolt hole. The main aim of his research was to develop a 3-D finite element model of an isolated region of the joint.

Fukuoka [9] in his research has analyzed the mechanical behaviour of the threaded bolted joints in various clamping configurations using FE model as a multi-body elastic contact problem. For studs and tap bolts he found the effects of nominal diameter, friction and pitch error up on stress concentration. With the increase of friction coefficient ($\mu$), the stress concentration at the thread root becomes remarkable. Contrary to this, it was observed that friction coefficient $\mu$ increases and the stress concentration factor decreases when the bolt head is subjected to pure tension. This type of opposing nature on the stress concentration factor observed at the bolt head and the root of thread may be because of the difference in sliding direction of these two regions, as the bolt thread slides inwards, and the bolt head extends outwards.

Pai and Hess [14] carried out extensive experiments on a simple nut and bolt assembly and also developed a three dimension finite element model to study details of four different loosening processes, characterized by complete or localized slip at the head and thread contact. They discussed the primary contact factor for loosening, and found that slip can occur at lower shear force then loosening caused by complete slip, and therefore critical in joint design. The finite element modelling is capable of predicting the different processes observed experimentally. The Finite Element modeling results capture the essential features displayed by the experimental data. The FE model includes the primary factor that cause loosening and provides a powerful tool for evaluation of the details of threaded fastener loosening.

Pai and Hess [15] also done study on loosening of threaded fasteners subjected to dynamic shear loads. The fundamental analysis of loosening was that a fastener can loosen at lower loads than previously expected, due to localized slip at the contact surfaces. Four different loosening processes of a screw under different conditions of slip at the head and thread contact regions are identified. Experiments were done and results illustrating these loosening processes were presented. In addition, the minimum dynamic shear force required to initiate loosening determined experimentally. The analysis presented in their paper illuminates the various causes of slip under shear loading.

Pai and Hess [17] has developed a non-linear three-dimensional finite element model that includes friction and contact was developed using the commercially available software, ANSYS, to determine the loads acting on the fastener in a compound cantilever beam subjected to a concentrated load at the end

Pratt [16] has shown that the primary reason of loosening is function of slip between the mating surfaces of the fastener. When sufficient force is applied in the transverse direction, the member moves in the transverse direction as well as in the downward direction. In a threaded bolt, the lead of the thread provides the direction for decreased potential energy, while the external loads provide the additional loads required to cause slip.

Menzemer [11] done his study on shear failure of aluminium connecting elements. An experimental and analytical method was used to study the shear failure of aluminium connecting elements. A study was conducted on the parameters like geometry of the specimen which include the variation in joint length, gage space of the fasteners and orientation of the specimen. Gage means the distance between fasteners lines.

Four different configurations of the specimen were examined, during the early stage of the tests; the curve between load displacements showed a progressive increase in slope, this type of behaviour is accounted to the removal of the slack from the load coupled with steady slip in the bearing.

An experimental study of self-loosening of bolted joints was developed by Jiang et al [18] they did work on Instron Machine. They showed that the self loosening process of a bolted joint consists of two distinct stages. The early stage occurs when there is no relative rotation between nut and bolt and due to cyclic plastic deformation of the materials. The second stage of self loosening is a result of gradual rotation of nut and characterized by the backing off the nut. The experimental set up was of two plates joined by a nut-bolt were subjected to cyclic transverse shear loading and relative displacement between the plates measured for different preloads.

Cope [19] developed a method to illustrate mechanical fasteners in a lap joint using finite element methods. The main aim of his research was to determine the appropriate level of model refinement needed for SFI solutions for the crack emanation at the fastener holes. It is well known that bolted joints are loosened when lateral loads are applied after they are tightened. As the result, the bolt loosening is caused by the shape of the thread that is the wedge inclined to the bolt axis. When lateral loads are applied, the bolt/nut threads slide relatively, which causes the relative nut rotation. When the loads are released, the bolt returns to the normal position keeping the relative slide to the nut. This nut rotation causes a reduction of the bolt tension, too. Although the magnitude of this rotation may be quite small, many times of repetition makes the bolt loosened. These are the findings of Shoji et al [20] in their studies.

Pai et al[15]in their research on Experimental Study of Loosening of Threaded Fasteners due to Dynamic Shear load concluded that the loosening rotation is caused by restoring action of an elastic torsion of a bolt shank which is due to relative motion at mating surface on threads.

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. [16]

The deformation behaviour of bolt-nut joint is depends on the amount of transverse load level applied on the joint. No slip generated at the bolt and nut bearing surface. Then, slip generated at the contact surface between fixed plate and movable plate when W exceeded the frictional force (Where frictional force = number of bolts, n X friction coefficient, μ X initial axial tension, $F_b$) is given to the joint.

However, when relative displacement, S between upper and lower plate is still small, by the bending deformation of the bolt, sliding at the bolt and nut bearing surface is not generated. Then, load and relative displacement between plates increased and at one stage relative displacement exceeded Delta S, slip is also occurs at the bolt and nut bearing surface. This slip leads to the reverse rotation of the nut and decrease the axial tension. The loosening behaviour of bolt-nut joint shows the same occurrence if the transverse load applied in the opposite direction. When transverse cyclic load applied to the joint, bolt axial tension slowly decreases and at the worst stage, not only loosening occurs but also the fatigue failure of the bolt. So, it is important to evaluate both loosening behaviour and fatigue failure of the bolt-nut joint.[25]

A study on high strength fastened joints using direct tension indicators [7] were done to know the transverse vibration loosening characteristics, the outcome was that with direct tension indicators loosening was less. A linear three-dimensional finite element analysis was performed by Srinivasan and Lehnhoff [13] on bolted pressure vessel joints to determine maximum stresses and stress concentration factors in the bolt head fillet. Their objective was to show the stress concentration factor. The models consisted of a segment of the flanges containing one bolt, using cyclic symmetry boundary conditions. The flanges were each 20 mm in thickness with 901.7 mm inner diameter. The outer flange diameter was varied from 1021 to 1041 mm in steps of 5 mm. The bolt circle diameter was varied from 960.2 to 980.2 mm in steps of 5 mm. The bolts used were 16-mm-dia metric bolts with standard head and nut thickness. This study showed that the traditional stress concentration factor might not be sufficient in the design of eccentric bolted joints, such as pressure vessel flanges.

Jung [12] by using fatigue modulus concept analyzed the fatigue life prediction of stainless steel (SUS304) with bolted joints. To consider the relaxation of steel concentration due to fasteners a modified, equation for fatigue life prediction as an exponential function of fatigue modulus, fatigue cycle and load transfer level was also derived. The main objective of this study was to characterize the fatigue behaviour of mechanically fastened joints, identifying the relaxation of stress concentration and the effect of the clamping force on the fatigue strength. In this study the plate type specimen with bolted holes was used for conducting fatigue tests and to observe the stress concentration near bolts for this finite element models were used. By the relaxation of stress concentration due to fasteners, extension of fatigue life was observed. Clamping force affects nonlinearly the slope of stress distribution.

An experimental study of self-loosening of bolted joints was developed by Jiang et al [10]. They did work on Instron Machine They showed that the self loosening process of a bolted joint consists of two distinct stages. The early stage occurs when there is no relative rotation between nut and bolt and due to cyclic plastic deformation of the materials. The second stage of self loosening is a result of gradual rotation of nut and characterized by the backing off the nut.

The experimental set up was of two plates joined by a nut-bolt were subjected to cyclic transverse shear loading and relative displacement between the plates measured for different preloads. They observed that there exist an endurance limit below which self-loosening would not persist and large preload resulted in a large endurance limit. But fatigue failure possibility of bolt increases at large preload, they suggested that the use of regular nut is better than the use of flanged nut. They used M12X1.75 nut bolts for their experiment. Studies on the other type of nut bolts are remaining to be done.

Cope et al [19] in their research have developed a methodology to study the stress intensity factors for crack at the fasteners in mechanically fastened joints. Stress intensity is mainly affected by geometric complexities, along with variations of load transfer in fasteners and fastener interface. A methodology was also derived using FE method, which depict mechanical fasteners.

Shoji and Sawa [20]. Several finite element analysis were performed and noticed that bolts are loosened or nut rotates, when the lateral loads are applied, based on this result, the mechanism of bolt loosening investigated. It was examined that loosening of bolt resists when double nut procedure is used.

Pratt [16] had developed a non-linear finite element models to investigate the load elongation behaviour of single and dual bolted conical head bolted lap joints. His study showed that the test specimen results of conical shaped headed bolts, the dual fasteners and the axis symmetric under estimated those of the single fasteners joints up to seventeen percentages in thick panels.

Chen et al. [21] have studied the failure of threaded fasteners because of vibrations; the main aim of their work was to study the loosening tendency of a threaded fastener. They have developed the looseness model, static and dynamic threaded bolt models were derived to found the static and dynamic interior forces respectively. Secondly, for investigating loosening of the bolt behaviour, initial preload, the effects of thread lead angle, vibration frequency and the nature of bolt material on the looseness of the bolt, the threaded fastener looseness model is constructed by combining all the above models with a Karnopp frictional model. This proposed approach analyzed both the static and the dynamic behaviours of the bolt along with the bolt loosening and also detected whether the bolt is within the elastic range or not.

Ibrahim and Pettit [22] reviewed and provided an overview of the problems pertaining to structural dynamics with bolted joints. They see problems are complex in nature because every joint involves different sources of uncertainty and non-smooth non-linear characteristics Under environmental dynamic loading, the joint preload experiences some relaxation that results in time variation of the structure's dynamic properties.

Drabek et al [23] investigated ductile damage in composite material reinforced with particle and fiber using FEA. This research study discusses the element removal technique triggered in a ductile damage indicator and versions of the ductile rupture modes. Fernando S. [24] in his research study showed the main predominant failure modes of bolted fasteners are fatigue failure due to loss of pre-tension and Loss of the threaded fastener.

Ganeshmurthy S. [25] conducted an experimental procedure and test set up was proposed to investigate the effect of under head contact radius, thread pitch, surface coating, and fastener head versus nut side tightening on the static and kinetic frictional torque components. He investigated the effect of tightening speed, coating, effect of repeated tightening and loosening.

A study of self-loosening of bolted joint was done by Kasei [26], when very small slippages occur repeatedly at bearing surfaces under transverse loads. He did some sample tests on setup and checked the loosening performance to show relative displacement between bolts and nut's threads drive. He performed experiments for M10 X 1.25 nut bolt. He inspected the anti-loosening performance of nut-bolt joint. The conclusion was when a high anti-loosening performance is required, a firm obstruction of the slippages at the mating surface on threads must be ensured.

To study the anti-loosening phenomenon of the threaded fasteners, a testing rig has been designed and fabricated by Saha et al. [27] where the clamping force can be continuously recorded under the application of accelerated known frequency vibration between two plates of nuts and bolt, the results obtained on the anti-loosening property of a number of threaded fasteners are presented, discussed and the effective one is found out. They concluded the nylon inserted nuts imparting higher frictional grip when fitted with standard metric bolt, the conventional BSW fasteners have shown lesser tendency to loosen.

J.A. Sanclemente and D.P. Hess[ 28] presented results from an experimental investigation of mechanical loosening in bolted joints due to cyclic transverse loads. They studied influence on the resistance to loosening of basic parameters such as preload, fastener material elastic modulus, nominal diameter; thread pitch, hole fit and lubrication. Sixty-four tests have been performed as part of a nested-factorial design in which the nominal diameter is the nesting factor of preload, thread pitch and hole fit. They found that the preload and the fastener elasticity are the most influencing parameters for loosening. A statistical model developed that predicts the level of loosening reached by a threaded fastener under defined conditions. The analysis shows that optimum conditions to avoid fastener loosening are high preload, low modulus of elasticity, large diameter, lubrication, tight fit and fine threads.

The mechanisms of loosening resistance components are investigated by Izumi and Sakai [29] and Izumi S et al. [30] with the three-dimensional finite element method. The results of the double nut tightening method, spring washers, and conical spring washers were shown. Their work focused on the comparison among the components based on the results. They found that double nut shows significant resistance of loosening if properly tightened. Spring washers show negative loosening resistance.

R. Friede & J. Lang [31] has taken especially the case in the field of bolts for steel structures with diameters of 16 to 36 mm, where the number of results is low. At risk for self loosening are steel structures under cyclic loads, such as cranes, mast constructions, smokestacks and bridges. To protect connections against the self loosening several anti loosening devices were on the market. Recent results showed that unfortunately almost all of them were malfunctioning. Due to that in 2003 all German regulations for these elements were withdrawn. At the moment a research project is running at the Technische Universität Darmstadt, Germany, to analyze the mechanism of self loosening. The aim is to find a constructive way to protect a bolted connection from self loosening. Therefore several tests to identify the important parameters were performed, especially the variation of the clamping length. Within the paper the results of the project so far were presented.

The loosening of screw fasteners is caused by two factors mainly. One is the relative slip between the bolt and nut screw threads, and the other is the relative slip between the nut or bolt surface and the surface of the fastened material. In their work Mahato and Das [32] the anti loosening ability of various 3/8 BSW locking screw fasteners with nylon nut, flat washer, nylon washer, serrated washer and spring washer are tested under accelerated vibrating conditions. The experiment has been carried out in an indigenously made testing machine. The initial clamping force given has been around 0.82 ton. Under vibrating condition, the loss of tightening force has been measured at regular intervals to adjudge the loosening of threaded fastener. From the results, it is observed that only small improvement has been obtained using flat washer over conventional nut. Outside serrated, spring and nylon washers show marginal anti-loosening ability. Nylon nut was seen to have better resistance to loosening than the other popularly known anti-loosening fastening elements tested, and hence, may be quite effective to use in vibrating conditions. However, other popularly known anti-loosening nuts or washers are found not to be that effective.

Kathryn J. Belisle [33] has done study on complete single bolted joint model incorporating the wheel rim flange and the two main loads seen at the bolted joints; bolt preload and the external load created by tire pressure on the wheel rim. A 2x3 full factorial DOE was used to establish the joint's response to various potential load combinations assuming two levels of preload and three levels of external load. The model was analyzed both experimentally and in finite element form. The strain results around the mating face radius were compared between the two analyses. Several parameters were identified that could affect the correlation between the results.

The finite element model was modified to incorporate each of these factors and the new results were compared against the original finite element results and the experimental data. The best correlation was found when the finite element model preload was adjusted such that the mating face radius strains under only preload matched those of the experimental results. The goal of thesis of Kathryn J. Belisle [33] was to establish a correlation between experimental and finite element strains in key areas of an aircraft wheel bolted joint. The critical location in fatigue is the rounded interface between the bolt-hole and mating face of the joint, called the mating face radius. A previous study considered this area of a bolted joint but only under the influence of bolt preload. The study presented here considered both preload and an external bending moment.

The study was done by Kadam and Joshi [34] on a bolted joint to determine the factors influencing the resistance of the bolted joint against vibration loosening. The results of their analysis using Taguchi method have been correlated using the reliability approach.

Eccles et al. [35] studied the loosening characteristics of prevailing torque nuts. They used a modified Junker test machine that allows the application of axial loading to a joint while experiencing transverse displacement. Tests have been completed using an intermittent as well as a constant axial load. Loading in both modes has been demonstrated to result in the complete detachment of this nut type. Based on this investigation, if the magnitude of the axial loading exceeds the residual preload in the bolt retained from sustaining transverse movement alone, the all-metal type of prevailing torque nut can completely detach. Applications that involve shear and axial loading being simultaneously applied to a joint are numerous in engineering. Axial loading applied while transverse joint slip is occurring also affects the loosening characteristics of standard plain nuts.

Based on the work of Junkers and other researchers, it is known that self-loosening of threaded fasteners can be prevented if sufficient preload is generated so that friction grip between the joint plates prevents the occurrence of transverse movement. In applications in which overload conditions can occasionally cause transverse joint movement, prevailing torque fasteners are frequently used in the belief that although partial loosening may occur, the nut will not become detached from the bolt. [24].

Hattori et al. [36] investigated the loosening and sliding behaviour of nut bolt fastener under transverse loading conditions. They showed that loosening behaviour of nut bolt joint shows the same occurrence if the transverse load applied in the opposite direction and when transverse cyclic load applied to the joint, bolt axial tension slowly decreases and at the worst stage not only loosening occurs but bolt fails in fatigue also. Medium carbon steel plates were used by them for fastened components and ordinary bolts of carbon steel, M6, M10, M16 were used for fastening. They showed that the outcome of the result can be used for CAE design tool for machine structure. Fatigue testing machine with hydraulic pump were used in order to generate transverse cyclic loading. Bolt nut joint with sensor and to measure fastening and bending stress a strain gauge mounted on bolt neck is used.

Soichi Hareyama [38] has done a detailed analysis of the joint. By his study it is possible to determine the clamping force required to be provided by the bolts to prevent joint slip. Threaded bolted joint problem occurs because it is always used at high stress values. These joints are subjected to vibrations repeated with external force. Further the effect of the pre load is actuated with increasing thread friction. Preload is the main economical way of prevention of vibration loosening. Transverse vibration loosening characteristic of bolted joints using multiple Jack bolt nut are also studied by Dalal U. et al [40].Patunkar M. Et al [37] has done studies on Modelling and analysis of composite leaf spring under the static load conditions.

Dravid S. et al[42] proposed a test set up to study the effect of loading on loosening of the bolted joint. KakirdeA. et al [44] reviewed on the contemporary research over this research topic.

# 3. CONCLUSION

The bolted joints are essential and critical elements of a machine or a structural assembly. The main purpose of the bolted joint is to transfer loads between different members of a structural assembly. Bolted joints transfer the given load from one part of the joined structure to the other joined part through bolt and this results bolt failure. There is vital necessity to optimize the design of these bolted joint, which will resulting in maximising of the load carrying capacity with structural integrity and to minimize the weight of the whole machine or structure. The mechanical joints are widely used in various bolted assemblies and this makes their design to be of great significance for both parameters which are cost reduction by saving in weight and, the prevention of failure.Failure can be either eliminated or reduced by washers. Many researchers work on this thought to improve the strength, efficiency & reliability by carrying out different experimental set up and studies. Furthermore there is a lot of scope in this field for new research work.

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