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Experimental Analysis of Damping on Layered & Riveted Joint Beam: A Review

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Abstract

The present investigation highlights the effect of interfacial slip on the damping of layered cantilever beams jointed with rivets undergoing free vibration. The inclusion of mechanical joints bears a strong influence in the overall system performance and behaviour, particularly the damping level of the structures. In fact, the damping and its improvement in machines or structures are one of the biggest challenges to the Practicing engineers. Usually, such structures inherently possess low structural damping necessitating the introduction of additional measures to improve their damping characteristics in order to control the harmful effects of vibration in normal operating conditions. Most of the damping in built-up structures is thus attributed to micro-slip at the interfaces. This design concept of using layered structures with riveted joints can be effectively utilized in trusses and frames, aircraft and aerospace structures, bridges, machine members, robots and many other applications where higher damping is required.

Keywords: Layered, cantilever beams, riveted joints and slip damping..

Introduction

Damping is a phenomenon where the amplitude of vibration in a mechanical system steadily diminishes. The effect of damping is to remove energy from the System. Damping is present in all vibrating systems. Every system which possesses mass and elasticity is capable of vibration. Therefore, damping plays an important role in the behaviour of any vibrating system. [10].Problems involving vibration occurs in many areas of mechanical, civil and aerospace engineering. Engineering structures are generally fabricated using a variety of connections such as bolted, riveted, welded and bonded joints etc. The dynamics of mechanical joints is a topic of special interest due to their strong influence in the performance of the structure. Further, the inclusion of these joints plays a significant role in the overall system behaviour, particularly the damping level of the structures. [7].In the present investigation, damping capacity of layered and jointed structures has been evaluated from analytical expressions developed in the investigation and compared experimentally for mild steel fixed beams with two or more layers under different conditions of excitation in order to establish the accuracy of the theory developed. [6]

Damping

Term damping refers to the energy dissipation properties of a material or a system under cyclic stress but excludes energy transfer device. When a structure is subjected to an excitation by an external force then it vibrates in certain amplitude of vibration, it reduces as the external force is removed. This is due to some resistance offered to the structural member which may be internal or external. This resistance is termed as damping. [7]

Classification of damping

Damping can be broadly divided into two classes depending on their sources,

MATERIAL DAMPING: Damping due to dissipative mechanism working inside the material of the member is termed as material damping.

SYSTEM DAMPING: System damping involves configuration of distinguishable part arises from slip and boundary shear effects of mating surfaces. Energy dissipation during cyclic stress at an interface may occur as a result of dry sliding (coulomb friction), lubricated sliding (viscous forces) or cyclic strain in a separating adhesive (damping in visco-elastic layers between mating surfaces). System damping to our need is classified as:

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- Support damping.
- Damping due to sandwich construction.
- Damping due to joints. [7]

Riveted joints

A rivet is a short cylindrical bar with a head integral with it. The set head is made before hand on the body of the rivet by upsetting. The second, called the closing head, is formed during riveting. A riveted joint is made by inserting rivets into holes in the elements to be connected. A joint holding two or more elements together by the use of rivets is called riveted joints. [10]

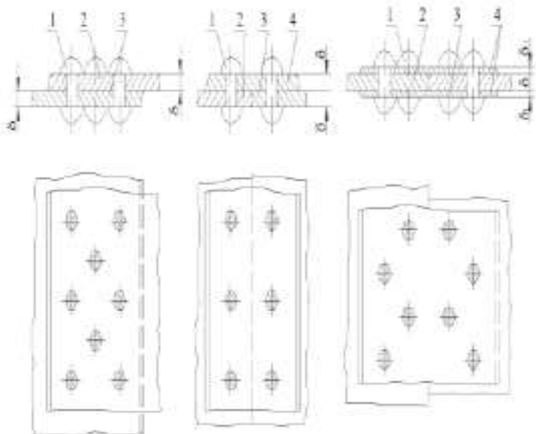

Figure-1.The ordinary forms of rivets after riveting.

Damping capacity of riveted joint

Damping capacity of a riveted joint depends mainly on the following factors:

1) Co-efficient of friction between joint surfaces
2) Micro-slip between joint surfaces.
3) Reaction force of a base applied during vibration.
4) Joint material, machining method of joint surfaces, interfacial layers, thickness of the beam, amplitude of vibration has large effect on damping and frequency.

Pressure distribution at the jointed interfaces

When two or more members are pressed together by riveting, a circle of contact will be formed around the rivet with a separation taking place at a certain distance from the rivet hole as shown in Figure. [6]

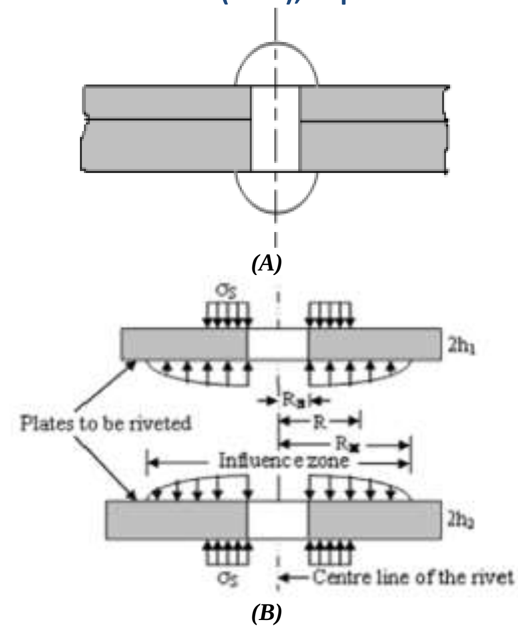

Figure 2. (A) Plates clamped by a rivet (B) Free body diagram of a riveted joint showing the Influence zone.

Mechanisms of micro-slip

Micro-slip is the normal mechanism by which mechanical joints dissipate energy and therefore, a better understanding of its phenomenon is required for the study of damping effects in the jointed structures. The contribution of the micro-slip on the overall system damping is significant in spite of its low magnitude and is generally promoted in structural joint designs. [7]

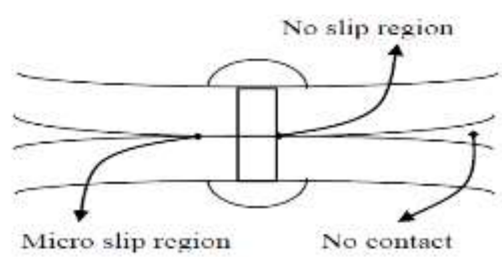

Figure 3. Mechanism of micro-slip at the jointed interface.

Damping ratio of beam

Recently demand for machine tools and fabricated structures having a high stiffness is increasing and it is widely recognized that the machine tools and fabricated structures should have a high static stiffness together with a light weight. For this purpose the riveted steel construction is very suitable, and then the use of machine tools made of riveted structures has been examined frequently up to the present. Many studies have been made on the sandwiched beam, the jointed beam and the laminated beam, and some of these beams have been already used practically. [10]

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Literature review

The following literature review describes important research results regarding the damping of layered and jointed cantilever beam.

- **Bhagat Singh, Bijoy Kumar Nanda (2012):-** It is quite evident that the relative slip increases with the distance from the fixed end. Moreover, the relative slip in multilayered cantilever beam is higher as compared to that of two layered beam at the same distance from the fixed end. In the multilayered beam there are multiple interfaces whereas in the case of two layered beam there is only single interface thereby increasing the relative slip in case of the former. That for the beam with the same total thickness, the loss coefficient is increased approximately 30% by having three rather than two equal laminates. However, for three laminates the onset of slip is delayed due to higher critical load, P=3Q/2 as compared to that of the two laminates where the critical load P=4Q/3 as evident from the expressions.[1]
- **Victor Hugo Dezotti, Leandro Ribeiro de Camargo, and Everaldo de Barros (2005):-** In this paper the effectiveness of a superficial viscoelastic damping treatment on the dynamic behaviour of flexible beams was investigated. A specific treatment in a constrained layer configuration was evaluated in an experimental study and provided a good alternative for the passive control of vibration of flexible beams, mainly on the higher modes, without representative structural characteristics changes. The experimental results obtained indicated that such treatment can be employed as an efficient damping mechanism on flexible and light structures.[2]
- **A.A. Ahmadi Asoor and M.H. Pashaei (2010):-** Damping is a complex phenomenon which acts in the form of absorption and dissipation of the energy in the vibrational systems. Different factors affect on the damping such as type of joints in the connections. In this research a comparison is made between welded and threaded (bolts and nuts) joints from the point of view of damping capacity. This paper presents the results of a number of dynamic tests conducted on two models. These models are similar in size but different in the connections. The damping ratios of these structures are determined using free vibration test method. The results obtained show that the threaded joints model experiences higher damping than the welded model.[3]
- **Jean-Luc Dion, Gael Chevalier, Nicolas Peyret (2013):-**This paper deals with the damping caused by friction in joints. A new test bench is presented and justified by comparisons made with devices described in the literature. The purpose of this academic bench is to measure the damping induced by partial slip and friction in a planar joint. Moreover, allows uncoupling normal static and dynamic tangential forces. A new method for so-called stopped-sine excitation was developed. It allows more precise monitoring of the evolution of the vibration frequency and damping of non-linear modes. This method is associated with piezoelectric exciters for greater efficiency when stopping excitation. A large number of experimental results are presented and discussed. They are used to characterize the damping induced by micro-sliding in the bonds.[4]
- **Bhagat Singh, Bijoy Kumar Nanda (2013):-** Welded joints are often used to fabricate assembled structures in machine tools, automotive and many such industries requiring high damping. Vibration attenuation in these structures can enhance the dynamic stability significantly. A little amount of work has been reported till date on the damping capacity of welded structures. The present work outlines the basic formulation for the slip damping mechanism in multilayered and welded structures, vibrating under dynamic conditions. The numerical Stability of the method and its applicability to actual working conditions have been investigated in the case of a tack welded cantilever beam structure with multiple interfaces. The developed damping model of the structure is found to be fairly in good agreement with experimental data.[5]

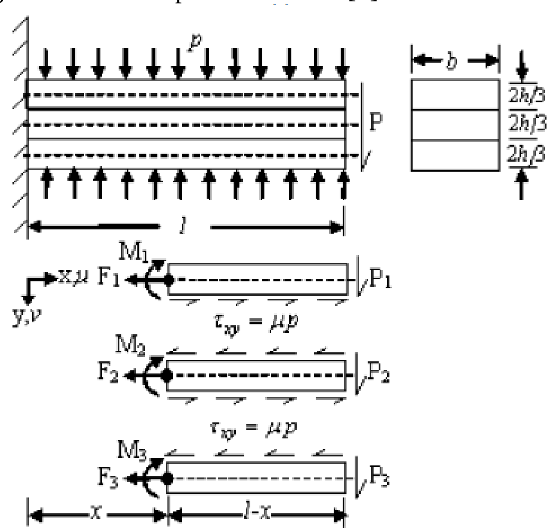

Figure.4 Three layers of the jointed beam depicting load and co-ordinates.

- **Sanpreet Singh Arora (2012):-** All materials posses certain amount of internal damping, which manifested as dissipation of energy from the system. This energy in a vibratory system is either dissipated into heat or radiated away from the system. Material damping or internal damping contributes to about 10-15% of total system damping. The main objective of this thesis is to estimate the damping ratio, natural frequency of aluminium, brass and steel by free vibration analysis experimentally & verify theoretically. Cantilever

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beams of required size & shape are prepared for experimental purpose & damping ratio is investigated. Damping ratio is determined by half-power bandwidth method. It is observed that damping ratio is higher for steel than brass than aluminium.[6]

- **Pavan Kumar Vodnala (2011):-** The damping mechanism of jointed and riveted structures can be explained by considering the energy loss due to friction and the dynamic slip produced at the interfaces. The frictional damping is evaluated from the relative slip between the jointed interfaces and is considered to be the most useful method for investigating the structural damping. The damping characteristics in jointed structures are influenced by the intensity of pressure distribution, micro-slip and kinematic coefficient of friction at the interfaces and the effects of all these parameters on the mechanism of damping have been extensively studied. All the above vital parameters are largely influenced by the thickness ratio of the beam and thereby affect the damping capacity of the structures. In addition to this, number of layers, beam length and diameter of connecting rivet also play key roles on the damping capacity of the jointed structures quantitatively.[7]
- **Harry Pierson, Jerald Brevick, and Kevin Hubbard (2013):-** The problem addressed in this work is the determination of the natural frequencies of transverse vibration for a Bernoulli–Euler beam. The equation of motion for a Bernoulli–Euler beam is given by

$$-EI\frac{\partial^4 y(x,t)}{\partial x^4}+f(x,t)=m\frac{\partial^2 y(x,t)}{\partial t^2}$$

Where E is Young's modulus, I is the polar moment of area for the cross section, f is an external force per unit length, m is the mass per unit length, and the coordinates (x, y) are defined as in figure below. [8]

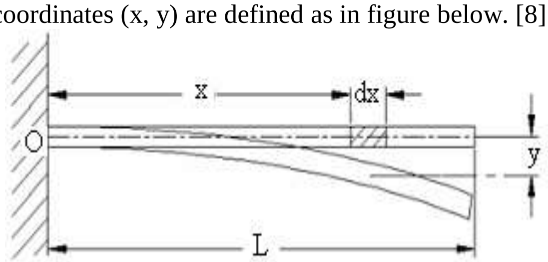

Figure 5. Differential analysis of a beam

- **Z.A. Jassim, N.N. Ali, F. Mustapha, and N.A. Abdul Jalil (2013):-** The important element in the research of vibration analysis for real engineering applications is a cantilever beam. The cantilevers should be more flexible in machineries and construction structures to be capable of withstanding high levels of stress and strain.[9]

Theoretical calculations

1. Natural frequency

For calculating natural frequency, first of all calculate stiffness i.e. K which is given by:-

$$K=\frac{3EI}{L^3}$$

Then calculate the natural frequency with the formula:-

$$\omega_n=\frac{1}{2\pi}\sqrt{\frac{K}{m}}\ \text{Hz}$$

2. Logarithmic Decrement (δ)

Thus, the logarithmic decrement δ is obtained as:

$$\delta=\ln\frac{x_1}{x_2}=\frac{2\pi\zeta}{\sqrt{1-\zeta^2}}$$

Where x_1 and x_2 are the successive amplitudes and ζ is the damping ratio.

In such a case,

$$\delta=\frac{1}{n}\ln\left(\frac{x_0}{x_n}\right)$$

Where x_0, x_n, and n are the amplitudes of first and last cycles and number of cycles, respectively.[6]

Conclusions

The results plotted in the figures and table show the coherence between the experimental and theoretical analysis. From the theoretical analysis, it is inferred that damping capacity of layered and welded structures can be substantially enhanced by fabricating the structures with multiple interfaces. It is also observed that onset of slip is delayed in the structures with multiple interfaces. However, the present work can be extended to evaluate the optimal number of layers to maximize the damping capacity considering the onset of slip with number of laminates. [1]

In this paper the effectiveness of a superficial viscoelastic damping treatment on the dynamic behaviour of flexible beams was investigated. A specific treatment in a constrained layer configuration was evaluated in an experimental study and provided a good alternative for the passive control of vibration of flexible beams, mainly on the higher modes, without representative structural characteristics changes. The experimental results obtained indicated that such treatment can be employed as an efficient damping mechanism on flexible and light structures. [2]

The frictional damping appears in the structure due to the sliding of the surfaces. The frictional damping together with the material damping forms the damping of the model. The damping

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deduced from the friction force is not presented in a welded joint. In other words, beside of the material damping which is present in the threaded joints model as well as the welded joints model, the threaded joints model experiences the frictional damping. This is why the capacity of damping in a threaded joint is higher than that of the welded joint. [3]

Finally, we suggest using this design and the experimental tools that have been developed to characterize the micro- sliding and the damping induced. Therefore the shape can be used to define specimens of several materials, roughnesses and flatness's, with or without coating, in order obtain a library of behaviors for use in the design of jointed structures. [4]

In the present work, a mathematical analysis has been carried out to investigate the mechanism of slip damping in layered and tack welded structures with multiple interfaces. Experiments are conducted to validate the theory developed. The results plotted in the figures show the coherence between the theoretical analysis and experimental results. From the theoretical analysis, it is inferred that the damping capacity of layered and welded structures can be substantially enhanced by fabricating the structures with multiple interfaces. It is also observed that the critical load is directly proportional to the square of the number of layers. [5]

Mechanical joints and fasteners are primary sources of improving damping in structural design caused by friction and micro-slip between the interfaces. The damping of jointed riveted structures has been studied theoretically considering the energy loss due to friction and the dynamic slip at the contacting layers. Further, the theoretical results obtained by using mathematical models have been verified by conducting extensive experiments for the validation of results. From the foregoing discussions, it is found that the damping of layered and riveted structures can be improved by the following influencing parameters: (a) amplitude of excitation, (b) frequency of excitation, (c) length of specimens (d) end condition of the beam specimen. Finally, it is established that a useful increase in the inherent damping in a jointed structure can be achieved at lower initial excitation, greater number of layers and larger length of specimens. The riveted structures being largely used in bridges, pressure vessels, frames, trusses and machine members can be effectively designed to enhance the damping characteristics so as to minimize the disastrous effects of vibration and thereby increasing their life. [7]

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