Global Journal of Engineering and Technology Advances

eISSN: 2582-5003

Cross Ref DOI: 10.30574/gjeta

Journal homepage: https://gjeta.com/

(Research Article)

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Experimental and simulation study on active vibration control of rotating machines using coconut-husk fiber composite

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Global Journal of Engineering and Technology Advances, 2024, 18(01), 068–074

Publication history: Received on 11 December 2023; revised on 22 January 2024; accepted on 25 January 2024

Article DOI: https://doi.org/10.30574/gjeta.2024.18.1.0016

Abstract

Vibrations may reduce the quality of products because of "chatter" during drilling operation, which may cause dimensional inaccuracy of drilled holes, poor surface finish, assembly, and operational problems. This therefore calls for the need for vibration absorbers or dampers. The drilling machine considered in this research was the MODIGS RBM 28B Radial Arm Drill. The vibrations during drilling operation of this machine were measured with the use of a Vibration Meter. This experiment was carried out on different metal workpieces which vary in their toughness and hardness; hence, the drilling machine was expected to vibrate with different amplitudes and frequency for these different metals.

In this experiment, Coconut Fibre was successfully simulated. The success was measured from how much of displacement the simulated coconut fiber composite absorbed and dampen down, keeping the machine to work at its optimum performance without excessive vibration, which normally could result to failure of machine components poor surface finish, and dimensional inaccuracy of holes.

Keywords: Vibration, fibre; Damping; Coconut-husk; Composite; Simulation; Epoxy-resin

1. Introduction

Vibration is present in countless daily life applications, and more often, it is highly undesirable and may decrease the performance of machine tools or cause machine components to fail. Vibrations may reduce the quality of products because of chatter during drilling operation, causing dimensional inaccuracy of drilled holes, poor surface finish, assembly, and operational problems. Vibration can occur in a variety of mechanical and structural systems. If the system is uncontrolled, catastrophe circumstance can happen because of the vibration such as vibration machine tool or machine tool chatter which can lead to defect in machining. There are various methods used to control the vibration. One of the commonly used is vibration neutralizer or vibration absorbers. Vibration absorbers are devices attached to the flexible structures to minimize the vibration amplitudes at a specified set of points [1]. The concept of vibration absorber is using a simple spring, mass, and damping elements to suppress the vibration of host structure. However, the major drawback of vibration absorber is only adapted to one single excitation frequency and not capable to reduce the global structural vibration comprehensively. This is where multiple passive vibration absorbers are obliged to achieve this objective [2].

Vibration damping could be active, passive or hybrid damping techniques. It is important to understand that the passive damping can control high-frequency excitation, while active damping can be used to control low frequency vibrations. Active vibration-reducing technique turns out to be a reality for a wide variety of applications. An active method integrates sensors and actuators with a flexible structure, operated by a control scheme. An essential issue in active control systems is sensors and actuator selection. The ever-increasing use of smart composite materials in advanced

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areas such as aerospace, automotive, and sports equipment has motivated researchers to explore behavior and performance characteristics.

In this study, a new control strategy is developed by using a small scale and lightweight passive vibration absorbers made from coconut husk composites to reduce the vibration of a beam structure. It is expected that by using multiple vibration absorbers, the vibration of beam structure can be reduced extensively. Since natural fibers have many advantages such as nontoxic, environmentally friendly, inexpensive, and low operation and production cost, they will be used as an alternative filler of composite material for making the absorbers system. The use of natural fibers in the manufacture of a product can contribute to a greener planet because it is a renewable resource and environmentally friendly. The products produced from natural fibers can be reproduced repeatedly and does not pollute the environment or cause of greenhouse gases [3].

Coconut coir fiber (CCF), or simply named as "coir" is coarse and short extracted from the fibrous outer shell of coconut. It is generally measured up to 35 cm in length with a diameter of 12-25 microns [4]. There are two types of coir; brown coir and white coir. Brown coir is harvested from mature coconuts. It is thick, strong, and high abrasion resistance. By contrast, smooth and finer whiter coir is harvested from immature green coconuts after soaking up to 10 months. It was reported that white is generally weaker than brown coir. There are other types of natural composites which include Polymeric matrix composites (PMCs) and epoxy resin which have been popularly used in infrastructure applications due to their many merits, including high strength to mass ratio, superior durability and easy in applications. Epoxy resins are considered as one of the most important classes of thermosetting polymers and widely used in various fields of coating, high performance, adhesives, and other engineering application. In usual applications epoxy resin are rarely used without the incorporation of some other materials. Filling are both used to enhance their performance by providing additional mechanical properties or modifying the physical characteristics of the blend. Raji et al, [5] evaluated the ductility and stiffness property of an Epoxy Resin reinforced Coconut Fiber. The study showed that, increase in length of fiber improves the ductility and stiffness properties of the composite material, which substantiated that coconut fiber, can be used to dampen vibrations of any vibrating body.

It is well known fact that vibrations contribute to excessive wear, fatigue failure and other premature failure of machine components. Thus, various methods have been applied to control these vibrations. One of the commonly used is vibration absorber was studied in Zamani et al, [4]. The study explored the potential of epoxy reinforced natural fibers as an alternative material for vibration absorber. Both mechanical properties and dynamic characteristic of the composites were investigated through tensile test and transmissibility test, respectively. Also, Sari et al, [6] investigated the acoustical and non-acoustical properties of composites using corn husk fiber (CHF) and unsaturated polyester as the sound-absorbing materials. The influence of the volume fraction of CHF on acoustic performance was experimentally investigated. The results show that the sound absorptions at low frequencies are determined by the number of lumens in fiber, particularly the absorption coefficient, which increases the amount of fiber. For high-frequency sound, the absorption coefficient is determined by the arrangement of fibers in the composite. Many researchers have been studying coconut fibers due to its being a natural and renewable source [7] and because coconut waste is discarded in landfills, bringing environmental problems the use of natural fibers such as coconut fibers has become industrially attractive because of its low cost, high availability, and desired mechanical properties for some applications, such as panels, ceilings, and partition boards and automotive components.

The effect of Coconut shell powder on the mechanical properties of coconut fiber reinforced epoxy composites has been extensively studied [8-10]. Coconut shell powder (filler) at different contents and various proportions of coconut fiber (reinforcement) had been used to prepare the epoxy composites. Composite samples were prepared using hand lay-up method and the test specimens were cut as per ASTM standards. Initially, tensile, flexural and impact properties of the samples were evaluated. It was found that the addition of filler had an insignificant effect on the mechanical properties. Flexural and impact properties also exhibited similar trends.

Coconut shells (CSs) are naturally occurring structural composites, which have a protective chamber for coconut fruit and its juice. A coconut fruit contains three layers, namely: endosperm, endocarp and mesocarp. The endosperm is the white and fleshy edible part of the coconut fruit harboring the coconut juice. The endocarp is the inner, hard lignocellulosic composite known as coconut shell and mesocarp is the ductile fibre-spongy husk called coconut coir [11]. CSs are agricultural wastes obtained from home and coconut processing industries after the edible parts have been removed. Coconut shell in its discarded form has little or no economic value. Their disposal is not only costly but may also cause environmental problems. Processing of coconut shells to obtain products such as CS (micro and Nano) particles, CS based carbon for engineering applications may add values to CSs and provide solutions to problems associated with their improper management. Report has shown that CSs contain carbonaceous materials such as cellulose, lignin and pentosans, which are potential materials for reinforcement [11-14] and Fibers from cellulose have been observed to contain a large variation in their mechanical and physical properties making it suitable in reinforced composite materials [15]. Globally, many researchers are now focusing on agricultural wastes such as coconut shell, palm kernel shell, banana peel, cashew shell, walnut shell, groundnut shells and Delonix Regia seed to replace highly expensive conventional glass and carbon fillers for polymer and metal matrix composite productions [12,14]. The agricultural wastes or natural fillers have advantages of low cost, high toughness, excellent specific strength, and enhanced energy recovery over conventional fillers.

Structural materials are subjected to many loading scenarios during processing and in service. Because of this, understanding the mechanical properties of polymeric composites to ascertain the loading constraint above which materials undergo plastic deformation and their predictions using an appropriate model is of significant benefits to service life of such materials to prevent catastrophic failures. In addition, polymeric composites usually degrade with temperatures. A prolonged exposure of the polymeric composites to high temperature application leads to progressive weakening of the cohesive forces holding the polymer molecules together and adhesives forces operating between polymer molecules and filler particles. Understanding thermal degradation process of polymeric materials and their wear resistance properties is fundamental to the design of polymer composites for automobile applications due to its exposure to environmental temperature variation and interaction with other materials at the installation point.

There have been substantive studies which addressed the excessive vibration of light structures and thin panel, which are commonly employed in automobiles and aircraft. Vibration control analysis for aircraft wing was done by Abdulameer and Wasmi [16] using smart material for active feedback control by output feedback system. Molina-Viedma et al, [17] exploits the response of a stiffened aircraft composite panel submitted to a multi-impact excitation, which is intended for impact and energy absorption analysis. Based on the high stiffness of composite materials, the study worked under the assumption that the global response to the multi-impact excitation is linear with small strains, neglecting the nonlinear behavior produced by local damage generation.

Generally, the standard solutions to eliminate and minimize the vibration are by redesign the system, stiffening the structure, applying damping materials on vibrating structure to dampen the response, and adding resonators such as vibration absorber to absorb vibration among other methods [18,19]. These requests promote the development of polymer composites-a combination of two or more materials, which has the potential to provide value-added properties absent in polymer [20].

This study tends focuses on the design and simulation of an active vibration absorber using coconut fiber composites for a MODIGS RBM 28B Radial Arm Drill. Ultimately, the goal is to measure the amplitude of the machine under drilling operation using a Vibration Meter, and thereafter simulate a vibration absorber using coconut fiber composites which can match up with the vibrations of the drilling machine to absorb the vibration caused by chatter to maintain its performance and enhance quality of machine tool products.

2. Methods and materials

The vibration amplitude of the MODIGS RBM 28B Radial Arm Drill under drilling operation on different metal work-piece materials was measured by experiment using a Vibration Meter. The workpiece prepared for the drilling operation are the aluminum, mild steel, galvanized steel, cast iron, stainless steel, and hard steel spring. The materials were prepared in the fitting shop to dimensions 100 × 50 × 10 (mm). The drilling operation using drill bits sizes 4, 5, 6, 6.4, 8.6, and 11 mm was done on the MODIGS RBM 28B Radial Arm Drill machine at the Mechanical Engineering workshop of University of Ibadan. The vibration readings were taking for each operation with the different drilling bits and workpiece. The vibration meter was attached to the drill head of the radial arm drilling machine for the readings.

The Radial Arm Drilling Machine was operated at a feed rate of 0.1mm/rev, and gradually lowered down as it drills through the 10mm thickness of the workpiece with the Coolant applied continuously until the hole is completely drilled. The Vibration Meter records the acceleration (in m/s^2), the velocity (in mm/s), and the displacement (in mm) of the Radial Arm Drilling Machine. The Radial Arm Drilling Machine was turned off after drilling has been completed. The operation was repeated without coolant.

The damping performance of the Coconut Fiber Composite was simulated in ANSYS using the polyurethane foam. The polyurethane foam is the material available on ANSYS with similar dynamic properties of the coconut fibre -epoxy resin composite as obtained in Raji et al, [5]. The static structural analysis, modal analysis, and harmonic analysis done on ANSYS for the composite by creating the composite mesh, support constrains, specification of the boundary conditions, loading, and solution generation.

3. Results and discussions

Table 1 and 2 shows the results of the amplitude of vibration and the frequency of the drilling operation. It is observed that the maximum displacement of the radial arm drilling machine 35.54 mm (0.03 Hz) and 128.33 mm (0.02 Hz) respectively occurred in the hard steel spring material during the drilling operation with drill bit of 6 mm for both coolant and no-coolant operation. The high values of displacement could be ascribed to the hard steel spring material toughness. It occurred that the drill bit 6 mm could not drill through the Hard Steel Spring material under the "no-coolant" drill condition. This was same for the consecutive drill bit sizes 6.4 mm, 8.6 mm, and 11 mm. The drill bits were only rotating without drilling through the material. The vibrations and the noise at this stage was very high that the machine had to be switched off to avoid any accident that may result from the drill bits breaking off and causing serious injuries.

Table 1 Experimental results for the "With Coolant" drill condition

	Drilling bit sizes					
	4 mm		**5 mm**		**6 mm**	
Workforce Materials	Displacement (mm)	Freq. (Hz)	Displacement (mm)	Freq. (Hz)	Displacement (mm)	Freq. (Hz)
Aluminum	0.025	13.01	0.028	14.47	0.03	15.91
Mild Steel	0.05	26.04	0.03	15.91	0.033	17.36
Galvanized Steel	0.028	14.47	0.025	13.02	0.033	17.36
Cast Iron	0.028	14.47	0.028	14.2	0.033	17.36
Stainless Steel	0.022	11.57	0.028	14.47	0.025	14.43
Hard Steel Spring	0.058	30.37	0.069	36.17	0.088	46.29
	6.4 mm		8.6 mm		11 mm	
Workforce Materials	Displacement (mm)	Freq. (Hz)	Displacement (mm)	Freq. (Hz)	Displacement (mm)	Freq. (Hz)
Aluminum	0.022	11.57	0.02	11.48	0.05	26.04
Mild Steel	0.022	11.57	0.025	13.02	0.025	12.89
Galvanized Steel	0.022	11.57	0.021	13	0.019	12.87
Cast Iron	0.022	11.57	0.02	11.51	0.027	14.2
Stainless Steel	0.024	13.02	0.028	14.47	0.036	18.81
Hard Steel Spring	.063	33.27	0.052	27.49	0.028	14.47

The issue here was not that the drill bits could not drill the Hard Steel Spring material as this was not the case with drill bits 4mm, 5mm, and 6mm (under With Cooling condition). The reason was because, according to drilling standard, the smaller the drill bit diameter, the higher the machine speed for drill, and vice versa, but in this experiment, equal speed of 440 rev/min was maintained for all the drill bits, regardless of the toughness of the different materials. This was so to obtain fair results. The hardness of material and diameter of drill bit determines the running speed of the machine (or spindle).

The results shows that Hard Steel Spring material has the highest amplitude displacement. This therefore served as our reference point in the simulation of a Vibration Absorber using Epoxy Resin reinforced Coconut Fiber.

The Coconut Fiber composite was simulated using ANSYS. The simulation results are as shown in Figures 1-3. Referencing the frequencies and amplitudes results gotten from the experiment, the simulation was designed to be able to absorb the highest recorded amplitude of 0.176 mm, as recorded under the Hard Steel Spring material specimen. The maximum deflection of the simulated fiber was 7.86×10^{-6} mm on subjection to the highest frequency of vibration of 92.59 Hz. This signifies the effectiveness of the simulated fiber in dampening the vibrations of the MODIGS RBM 28B Radial Arm Drill. Because the material specimens under which the vibrations of the machine were tested were not the toughness, the simulated Coconut Fiber composite was designed for higher frequency of up to 1000Hz.

Table 2 Experimental results for the "Without Coolant" drill condition

	Drilling bit sizes					
	4 mm		**5 mm**		**6 mm**	
Workforce Materials	Displacement (mm)	Freq. (Hz)	Displacement (mm)	Freq. (Hz)	Displacement (mm)	Freq. (Hz)
Aluminum	0.030	15.91	0.025	13.02	0.033	17.36
Mild Steel	0.066	34.72	0.028	14.47	0.026	14.30
Galvanized Steel	0.061	31.83	0.028	14.47	0.030	15.91
Cast Iron	0.022	11.57	0.028	14.2	0.033	17.36
Stainless Steel	0.021	11.55	0.028	14.47	0.025	14.43
Hard Steel Spring	0.020	11.47	0.069	36.17	0.088	46.29
	6.4 mm		8.6 mm		11 mm	
Workforce Materials	Displacement (mm)	Freq. (Hz)	Displacement (mm)	Freq. (Hz)	Displacement (mm)	Freq. (Hz)
Aluminum	0.022	11.57	0.021	11.55	0.020	11.47
Mild Steel	0.022	11.57	0.025	13.02	0.023	13.00
Galvanized Steel	0.022	11.57	0.025	13.02	0.024	14.20
Cast Iron	0.022	11.57	0.02	11.51	0.027	14.2
Stainless Steel	0.024	13.02	0.028	14.47	0.036	18.81
Hard Steel Spring	.063	33.27	0.052	27.49	0.028	14.47

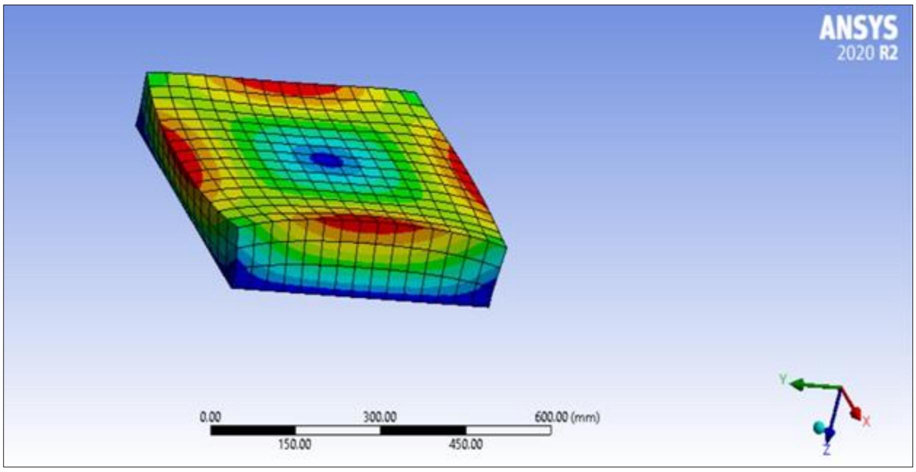

Figure 1 Simulated Coconut Fiber composite with maximum displacement of 7.86×10^{-6}mm

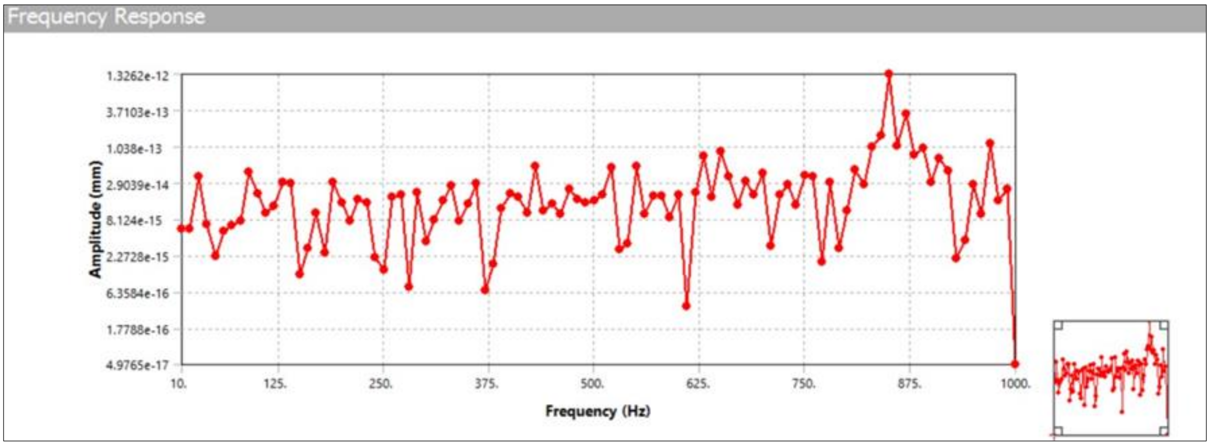

Figure 2 Frequency response of the simulated Coconut Fiber

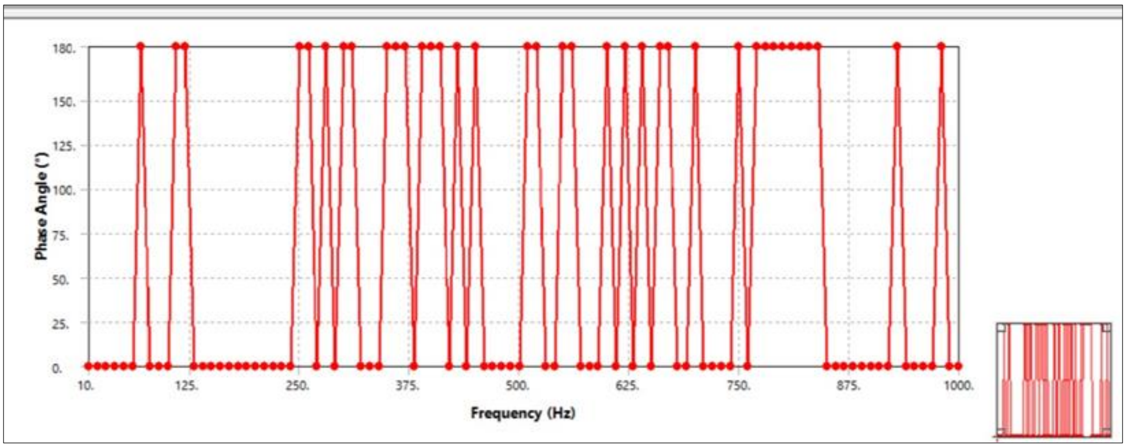

Figure 3 Phase angle response of the simulated Coconut Fiber

4. Conclusion

A Coconut Fiber has been successfully simulated. The success of this could be seen from how much of frequency the simulated fiber could take in and dampen down, with very small displacement, keeping the machine to work at its optimum performance without excessive vibration, which can result to failure of machine components, poor surface finish, and dimensional inaccuracy.

This simulation can be used by the manufacturer of the MODIGS RBM 28B Radial Arm Drill or users to fabricate a vibration damper for their machine. The damper can serve as an added unique value proposition (UVP), to help them capture the market for their machine as MODIGS RBM 28B Radial Arm Drill is not the only radial arm drilling machine in the market.

Compliance with ethical standards

Disclosure of conflict of interest

No conflict of interest to be disclosed.

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