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A novel bio-inspired anti-vibration structure for operating hand-held jackhammers

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A B S T R A C T

Long-term exposure to high level vibration can lead to considerable pain and time off work, and even result in permanent disability. Therefore, vibration protection to operator when operating vibrating tools is a very important issue in construction. Targeted at operating heavy-duty jackhammers or road breakers etc, an innovative anti-vibration exoskeleton technology is successfully developed in this study, which is passive, portable, cost-efficient and crucially helpful for a significant vibration suppression during the drilling and hitting process. To explore the benefits of nonlinear dynamics and passive structure design in vibration control, the innovative anti-vibration exoskeleton is designed for the first time to mimic the limb structure of animals and fully employs the beneficial nonlinear benefits in the bio-inspired anti-vibration structure which can consequently significantly reduce vibration transmission without sacrificing loading capacity, while the latter is very important to increase the demolition efficiency during a demolishing work. Theoretical modeling, simulation and experiment results demonstrate the effectiveness and efficiency of this innovative technology, consequently solving such a long-time existing engineering problem in the construction field.

1. Introduction

In most engineering practice, mechanical vibration is regarded as a negative issue. It will affect mechanical properties, aggravate fatigue and wear, even cause the destruction of structures. Moreover, vibration-related syndrome to human bodies includes damage to sensory nerves, muscles and joints in the hands and arms. Working in construction, engineering, agriculture and mining is well recognized as being at these risks. Therefore, vibration protection to operator body when manipulating vibrating tools is a very important issue, which is not only related to body physical and mental health but also affects working efficiency and manpower loading etc.

Installment of vibration isolators is a common method for vibration control. It refers to the techniques of reducing vibration transmission by inserting stiffness or damping devices between vibration source and receivers. With the development of vibration control theory in the past decade, more and more results indicate that traditional linear isolators are very limited to meet the increasing demands of high vibration control performance, while nonlinear vibration control has been attracting more and more attentions in the analysis and design of various vibration control or isolation systems [1–9], in extensive engineering practices from vehicle suspension, high-precision machines, to space lunching or on-orbit vibration control etc.

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As early as 1971, Ruzicka and Derby [6] discussed the attenuation of forces in linear and nonlinear systems. In 1978, Dange and Gore [7] analyzed the nonlinear isolator by the computer simulation method. In 1979, Hundal and Parnes [8] studied the dynamic responses of the isolator in the same system under the basal vibration conditions to prove that the vibration isolation effect of the nonlinear system is significant. In 1997, Nayfeh et al. [9] designed a nonlinear mechanical isolator containing different factors as discrete quality, stiffness, damping and so on. They made the system contain nonlinear features in a small range to reduce the vibration transmissibility greatly for the harmonic excitation by a suitable nonlinear stiffness setting. In recent years, more and more attentions are attracted to the nonlinear vibration control systems. Several recent review papers can be seen in [1–3], serving good summaries of recent advances in this active area.

It is noticed that very good passive vibration control performance is possible in case that nonlinear dynamics can be fully employed through a feasible structure design. Some recent works including quasi-zero or zero stiffness systems, or high-static low-dynamic stiffness systems in [10–12] demonstrate this idea very clearly. A series of recent studies in [13–17] present a bio-inspired X-shaped structure approach which naturally combine the advantageous benefits of nonlinear dynamics and feasible structure design together in a purely passive manner achieving very excellent vibration control performance.

In this study, the bio-inspired anti-vibration structure is innovatively applied to solve a vibration suppression problem extensively existing in all hand-held demolition tools in construction, which is a troublesome issue ever perceived for a long time in the area. Construction workers manipulating heavy-duty jackhammers or road breakers receive excessive vibration to hand and arms, eventually leading to serious vibration-related syndrome (Fig. 1). It is known that the most harmful vibration is in the frequency range between 4 Hz and 50 Hz [18,19]. However, the traditional springs or dampers applied in a traditional way cannot solve the problem due to that (1) the worker needs to press down to hold the machine tightly in order for high demolition efficiency and (2) more compression in traditional springs or materials leads to dramatically increasing stiffness and consequently serious downgrade of vibration suppression. Therefore, market products with different active vibration control appear but extremely increase the cost in manufacturing and maintenance still with quite limited reduction of practical vibration level.

To solve this troublesome problem, an innovative passive anti-vibration exoskeleton is therefore developed in this study based on the bio-inspired X-shaped structure, referred to bio-inspired anti-vibration exoskeleton (BIAVE) (Figs. 2 and 3). The BIAVE is consisted of two X-shaped structures in parallel with several layers and springs installed each, which is also lightweight, foldable and adjustable in size and stiffness and thus adaptive to be used for different jackhammers. Due to the beneficial nonlinear stiffness of the X-shaped structure, the vibration in jackhammers would be significantly reduced when transmitted to the operator handles because of the quasi-zero stiffness purposely created. Moreover, when the operator pressed down the handles of the BIAVE, more downward forces would be added to the jackhammer which increase demolition efficiency, but the dynamic stiffness between the jackhammer and the BIAVE handles can be obviously decreased instead of increased due to the very special nonlinear feature possessed by the BIAVE. These exactly solve the challenging issues mentioned above. Modeling, analytical analysis and experiments are systematically conducted in this paper, including structure design, parameter influence, and dynamic modal analysis etc, which all demonstrate the significant performance of this novel BIAVE technology.

Fig. 1. Demolition in construction with a jackhammer.