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Research paper

Suspension mechanical performance and vehicle ride comfort applying a novel jounce bumper based on negative Poisson's ratio structure

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A R T I C L E I N F O

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A B S T R A C T

Comparing with traditional honeycomb structures, Negative Poisson's Ratio (NPR) structures had better mechanical performances in some certain respects, especially the shear modulus and fracture toughness. However, few publications focused on the cylinder-shape NPR structure, which influence the diversity and possibility of NPR structure applications. In this paper, a cylindrical NPR structure was introduced and applied as a suspension jounce bumper in order to solve the issue that the ideal uniaxial compression load-displacement curve sometimes cannot be realized by traditional Polyurethane (PU) jounce bumper. The load-displacement curve of NPR jounce bumper was proved to be smoother and more ideal than that of traditional jounce bumper. Nevertheless, the influences of NPR jounce bumper on the suspension mechanical performance and vehicle ride comfort were not comprehended yet. In this study, the traditional and NPR jounce bumpers were both assembled into virtual prototypes of Macpherson, double wishbone and multi-link suspensions to conduct single wheel travel virtual tests. The results indicated that NPR jounce bumper can achieve more ideal wheel force vs. jounce height curve without adjusting free travel, which is beneficial to spare precise suspension space. Furthermore, a jounce bumper evaluation method using pulse ride comfort was proposed in this paper. The virtual ride comfort tests of travelling through bump and pothole were conducted using established vehicle virtual prototype. The maximum vertical accelerations and weighted root mean square (RMS) of acceleration of vehicle centroid at most speeds were reduced applying NPR jounce bumper. Thus, the NPR jounce bumper can apparently improve vehicle ride comfort.

1. Introduction

Jounce bumpers are an essential component in vehicle suspension systems, and primarily used to attenuate impact energy and improve ride comfort performance during transient pulse impacts from roads. Jounce bumpers are usually manufactured from Polyurethane (PU). Moreover, jounce bumpers sometimes even act as an assistant spring collaborated with the main coil spring. The main design variables of the jounce bumper are its geometry and material properties that all significantly influence the mechanical performance of jounce bumper [1]. The most concerned property of jounce bumper is its nonlinear uniaxial load-displacement curve which is normally obtained through experimental or numerical methods [2]. Generally, the design target of jounce bumper is to achieve an ideal load-displacement curve that is sometimes unreachable by traditional PU jounce bumper.

Kim et al. [3–5] researched the influence of the load-displacement curve of jounce bumper on the suspension mechanical performance in MSC.ADAMS. It was proved that the load-displacement curve of jounce bumper is significant to the suspension mechanical performance and the vehicle ride comfort performances. Therefore, the jounce bumper must be taken into consideration in the dynamic analysis of suspension and entire vehicle. Goh et al. [6] performed dynamic analysis of Macpherson suspension using the load-displacement curve of jounce bumper obtained from quasi-static compression test. The dynamic load of jounce bumper was calculated by a classical viscoelastic Voigt model. Xiao and Fang [7] conducted random excitation simulation of a four degrees of freedom (DOF) half vehicle model including jounce bumper. The results indicated that the jounce bumper can apparently improve the vibration attenuation and ride comfort performances.

In addition, jounce bumper is only compressed at large positive vertical wheel travel [6]. It mostly works under pulse excitation conditions which is one of the most important aspect of ride comfort [8,9]. Thus, it is necessary and significant to analyse the jounce bumper under pulse excitation conditions. Liu and Dong [10] analysed the impact probability of jounce bumper under rough road condition in view of the durability of jounce bumper, and researched the influence of suspension

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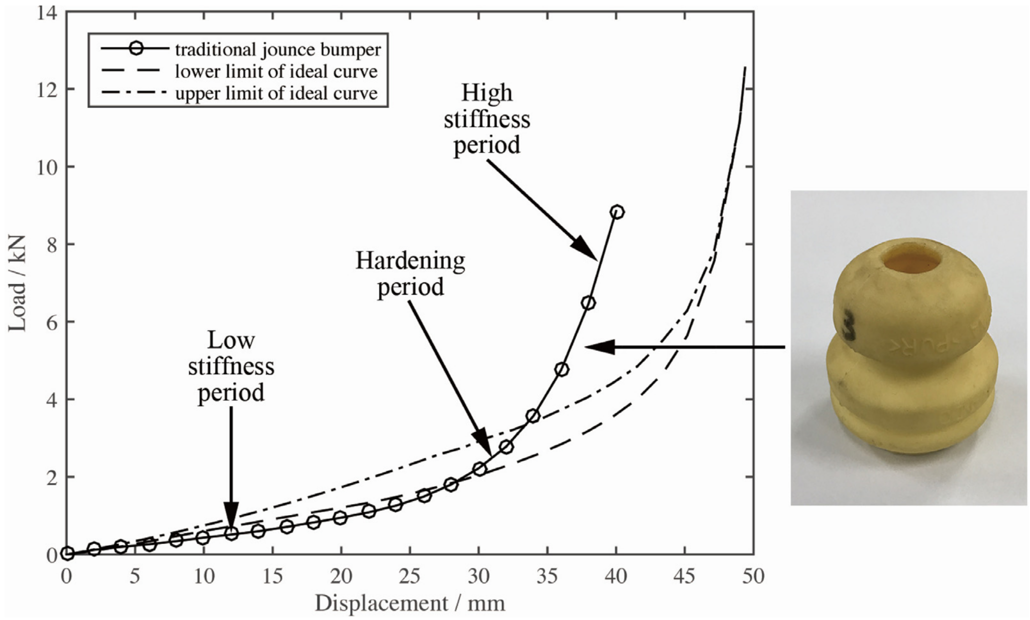

Fig. 1. Uniaxial load-displacement curve of traditional PU jounce bumper and ideal curves.

free travel on ride comfort performance. Li et al. [11] optimized the jounce bumper stiffness and suspension free travel and performed pulse and random roads ride comfort analyses. It was concluded that optimization of stiffness is more efficient to improve ride comfort performance than suspension free travel.

The load-displacement curve of a traditional PU jounce bumper combined with the lower and upper limits of ideal curve provided by an automotive company were shown in Fig. 1. The load-displacement curve was separated into three periods. The first and last periods are the low and high stiffness regions. And a hardening period where the stiffness suddenly rise is located between the low and high stiffness periods. As shown in Fig. 1, the hardening period of PU jounce bumper appeared earlier than the ideal curves, which is the primary issue of traditional jounce bumper. It should be mentioned that the ideal hardening period can be realized by enlarging the entire height of jounce bumper. However, the total height of jounce bumper is strictly limited or even fixed due to the precious suspension space. On the other hand, stiffness is not a problem of traditional jounce bumper. Since stiffness can be enhanced or weakened by the tuning of PU material manufacturing parameters.

Owing to the commonly unreachable ideal load-displacement curve, new jounce bumper designs should be applied to solve this issue. Schudt et al. [12] proposed a dual rate jounce bumper that an extra energy absorption component was added. This novel concept was applied on several General Motors vehicles, and achieved smoother load-displacement curve and better suspension system durability than single component jounce bumper design. Wang et al. [13] proposed a cylindrical Negative Poisson' Ratio (NPR) structure and applied this novel structure as suspension jounce bumper [14,15]. It was concluded that the load-displacement curve of the NPR jounce bumper was more ideal than that of traditional PU jounce bumper, and the hardening period appeared later.

NPR structures are novel types of structures that had great mechanical performances [16–19]. Poisson's ratio reflects the relationship between lateral deformation and longitudinal deformation, and is positive in almost all natural materials. However, NPR materials and structures exhibit opposite behaviour to normal materials and structures. They expand laterally under tension load, while shrink laterally under compression load. In 1987, Lakes [20] developed a NPR polyurethane foam, which is the first time that NPR materials was fabricated. Since then, various types of NPR materials and structures were proposed and researched. NPR structures mainly includes reentrant hexagonal honeycombs [21–23], double-arrow honeycombs [24], chiral honeycombs [25–29], rotating unit structures [30–32], hollow sphere structures [33,34], porous structures [35–38], etc. Elipe and Lantada [39] researched the differences in mechanical performances between several types of two-dimensional and three-dimensional NPR structures. Maximum area reduction, effective Poisson's ratio and effective Young's modulus of all cases were studied. It was proved that the reentrant hexagonal and double-arrow NPR structures owned the largest effective Young's modulus which is at least 10 times the other types. The maximum area reduction and effective Poisson's ratio of these two types were also excellent compared with other types. As a result, reentrant hexagonal and double-arrow NPR structures were especially suitable for load bearing components among all NPR structures.

Reentrant hexagonal NPR structures are the most popular NPR structures and draw lots of attentions. However, when applying to jounce bumper, reentrant hexagonal lattice exhibits some deficiencies. As shown in Fig. 2(a), if the reentrant hexagonal structure was uniaxial compressed along vertical direction, buckling of red vertical beams influences the instability of entire structure. If the reentrant hexagonal structure was uniaxial compressed along horizontal direction, the transverse zigzag beams will fold together according to Fig. 2(b). And the hyperelastic materials were not applicable due to their low resistant for bending or rotating. As shown in Fig. 2(c), the tendon layers in double-arrow NPR structures were stretched under vertical load. When applying hyperelastic materials, great stiffness and damping performances can be expected.

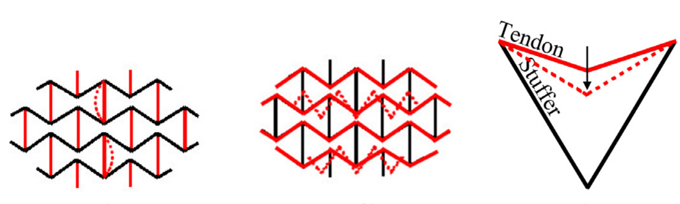

Fig. 2. (a) Buckling of vertical beams of reentrant hexagonal structure under vertical uniaxial compression (b) folding of transverse zigzag beams of reentrant hexagonal structure under lateral uniaxial compression (c) stretching of tendon layers of double-arrow NPR structure.