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High-Static-Low-Dynamic Vibration Isolator Component Designed By Topology Optimization with Hyperplastic Material

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Extended Abstract

High-static-low-dynamic-stiffness vibration isolation systems can afford payload at static stationary conditions and avoid payload from vibration [1]. A type of high-static-low-dynamic-stiffness passive vibration isolation system is composed of simple springs set to protect payload objects placed on top of it from vibration. One of the ways to construct high-static-low-dynamic-stiffness mechanism for low-cost scenarios is by implementing negative-stiffness components for achieving quasi-zero stiffness mechanisms [2]. As a preliminary research for the whole quasi-zero stiffness vibration isolator, this study is with a view to constructing a method to design negative-stiffness compliant structures for compensating linear positive support sprint to satisfy quasi-zero stiffness conditions. The negative-stiffness components are designed as 2D compliant structures by topology optimization method [3] in this study. The simulation results of the compliant structures were finally compared with the fused deposition modeling with hyperplastic material TPU 95A from Ultimaker [4] by Ultimaker 3. This study started with 2D finite element simulation with linear material property for topology optimization and gradually estimated the error between 2D and 3D simulation results, the influence of Young's modulus and Poisson's ration variation on the compliant structures, and the error between linear/hyperelastic material in 3D simulation and the experimental results.

The negative-stiffness compliant structures were designed according to the concept of a bi-stable snap-through structure, which guarantees the negative-stiffness property between the two bi-stable points. By maximizing the load difference between two bi-stable points, this study aims to maximize the performance of the negative-stiffness property of the compliant structure in a specific displacement working range. The lower the negative stiffness, the higher the affordable payload for high-static-low-dynamic-stiffness vibration isolator. During the optimization process, this study also prevented the situation that a bi-stable snap-through compliant structure cannot resume to the initial unloaded point, which is due to a part of negative-stiffness region located in the negative load. 2D plane stress, 2D plane strain, and 3D simulations were compared with the same 2D optimally designed compliant structure layout. The case study in this research revealed that the 2D plane strain is closer to the 3D result with a lower Poisson's ratio around 0.3; however, the error was increased when Poisson's ratio rose to 0.45.

Another error that causes the gap between simulation and experiment is material properties. Fused deposition modeling TPU 95A constructed layer by layer as a transversely isotropic material instead of isotropic. This study followed ASTM D638-14 [5] for tensile testing and ASTM D575-91 [6] for compressive testing. According to ASTM D5323-92 [7] for determining 2% secant modulus in tensile testing and cutting off the "toe region" defined in ASTM D575-91, the final fusion stress-strain characteristic curves are close to the ideal Neo–Hookean hyperelastic material. Besides, the experimental Young's modulus in simulation was also corrected according to the experimental results. In the advanced study, applying hyperelastic material property with the final corrected material modulus made the 3D simulation even closer to the

experimental results. This study also built a quasi-zero stiffness vibration isolator in physical and practiced impact and excitation testing for preliminary quasi-zero stiffness property confirmation.

References

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