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Experimental investigation and modeling of dynamic performance of wave springs

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Abstract. This paper investigates vibration suppression potentials for a novel frictional system - a wave spring. Two different types of wave springs, crest-to-crest and nested ones, were used in this work. Compared with nested wave springs, crest-to-crest wave springs have lower damping and a larger range for the linear stiffness due to a reduced level of contact. Dynamic compressive tests, subject to different static compression levels, are carried out to investigate the force-displacement hysteresis of individual wave springs. The stiffness is shown to increase up to 800% when the static compression is at 40%. The crest-to-crest wave spring is shown to provide loss factors up to 0.12 while nested ones as high as 0.80. Testing also showed that performance did not degrade between room temperature and 100°C. The effect of different spring materials, inner diameter and flat spring width are also evaluated.

Introduction

A wave spring, as shown in Figure 1, can be used as an alternative for a helical spring. The wave spring is a circular, metal compression spring, whose coils are constructed from a fixed-width metal strip that is formed into a sinusoidal wave [1]. The stiffness and damping of wave springs are deflection dependent due to the introduction of contacts and sliding between different layers of metal [2]. The energy dissipation of a wave spring is considerably higher than that of a classic coil spring. One potential application for these wave springs is a TMD. The nonlinearity and damping present in wave springs give them the potential to increase the effective frequency range of a TMD when used as a combined stiffness and damping element while their metallic construction offers an increased operational temperature range. The objective of this paper is to investigate the stiffness and loss factor of wave springs and to develop models that represent them analytically and numerically.

Fig. 1 Wave spring models for (a) crest-to-crest wave spring and (b) nested wave spring

Results

To identify the force-displacement hysteresis properties of waves springs, dynamic compressive tests were carried out using a uniaxial hydraulic test machine. The typical hysteresis loops are shown in Figure 2.

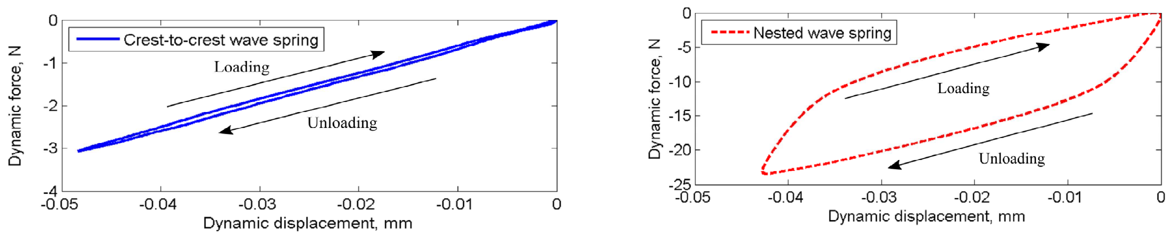

Fig 2. Typical hysteresis loops for wave springs subjected to a strain of 0.35 for (a) crest-to-crest wave spring and (b) nested wave spring

It can be seen from Figure 2 that nested wave spring shows classic friction interface behaviour and can provide higher damping than the crest-to-crest wave spring. For the crest-to-crest wave springs, the characteristics of sliding friction are not obvious due to the small areas of contact leading to relatively low levels of damping present. As the static compression increases, more relative movements in the contact area develop for nested wave springs.

Since nonlinear stiffness for these wave springs are of interest, different excitations, for instance static compression, were used in this work. The excitation frequencies for these tests are 2.5 Hz. For each test, 100 sinusoidal cycles were obtained and the ensemble average of 96 waveforms was used to estimate the hysteresis loop. Note that a low-pass Butterworth filter, with a cutoff frequency of 50 Hz, was applied to the force and displacement signals to remove the noise from sensors. This filter was shown to have a negligible effect on prediction of the damping and stiffness for this dynamic system. The stiffness and loss factor at various strain amplitudes are shown in Figure 3.

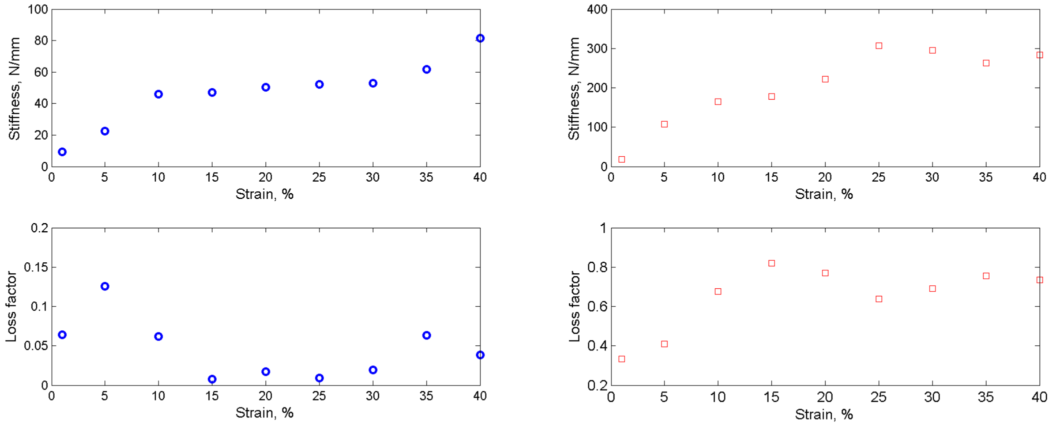

Fig. 3 Effect of static compression for (a) crest-to-crest wave spring and (b) nested wave spring

It is interesting to note that the stiffness and static compression fit a piecewise linear model. Additionally, the highest stiffness for the nested wave springs is around 300 N/mm at 25% strain and then remains nearly constant through 40% strain while the crested wave spring reaches 80 N/mm at 40% strain level. Considering mechanical systems, wave springs can provide useful stiffness variations and can work as effective energy dissipation devices.

For the condition where the ambient temperature is 100°C, the tests were carried out at different pre-strains. Results are presented in Figure 4.

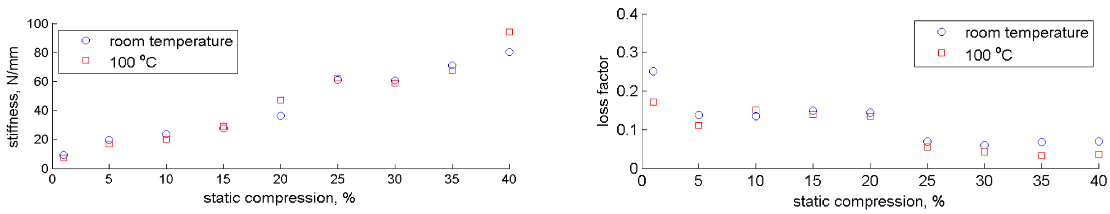

Fig. 4 Effect of temperature for crest-to-crest wave springs for (a) stiffness and (b) loss factor

Figure 4 indicates that there is no obvious change for the stiffness or damping between room temperature and 100°C.

The FE model was then established using ANSYS commercial FE code. Since these wave springs are oil finished, frictional coefficients between two neighbouring metal strip need to be estimated. Several static compressive tests were used to gain these important parameters. Results indicated that the stiffness and energy loss predicted by FE code were almost the same with experiment results. Following that, the analytical model for the wave spring was modelled using a Maxwell slider model [3], as shown in Figure 5. Using a differential evolution algorithm, the stiffness and frictional force were identified from the FE models.

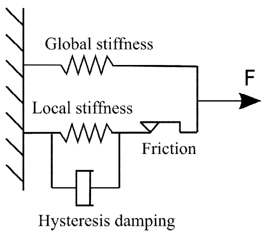

Fig. 5 Maxwell slider model

Conclusion

In this paper, the stiffness and damping properties for two different types of wave springs are investigated. It is highlighted that the stiffness and loss factor of the wave springs remain unchanged when the temperature increases. The nonlinearity of wave springs expands the working frequency ranges when these elastic components were used as vibrational dampers. Using FE and the analytical model, the stiffness and damping properties of these wave springs was predicted within a reasonable accuracy.

Reference

[1] E. Dragoni: *A contribution to wave spring design*, J. Strain Analysis for Engineering Design, Vol. 23(1988) p. 145-153.

[2] N. Tang, J.A. Rongong and G.R. Tomlinson: *Nonlinear behaviour of tangled metal wire particle dampers*, in Proceedings of International Conference on Structural Engineering Dynamics, Lagos, Portugal, 2015.

[3] V. Lampaert, J. Swevers and F. Al-Bender, *Modification of the Leuven integrated friction model structure*, Automatic Control, IEEE Transactions, Vol. 47 (2002), p 683-687.