

## GEOMETRICALLY NONLINEAR HENCKY BEAM WITH A TIP-MOUNTED SHEAR-THICKENING FLUID DAMPER UNDER HARMONIC BASE EXCITATION

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### ABSTRACT

A geometrically nonlinear beam equipped with a tip-mounted shear-thickening fluid (STF) damper is investigated under harmonic transverse base excitation. To accurately capture large deflections, the beam is modeled using Hencky's discretization [1], which replaces the continuous structure with a chain of rigid links and rotational springs. The governing equations are derived using Lagrange's formulation in a nondimensional form and solved numerically via time integration while sweeping the excitation frequency. The study compares two right-end boundary conditions: a completely free tip and a horizontally constrained tip (allowed to move vertically but not longitudinally). We observe that horizontally constraining the tip stiffens the system, shifting the dominant resonance to higher frequencies and enhancing the nonlinear hardening behavior.

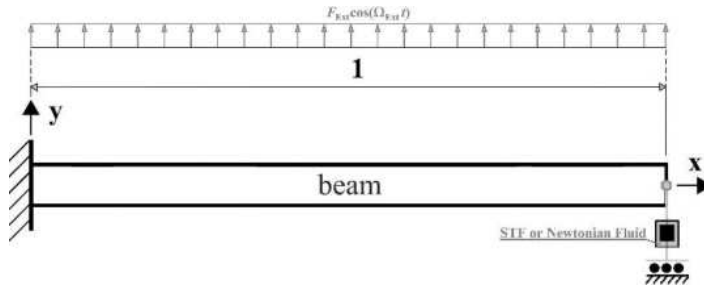


Fig. 1. Schematic of the free-end beam configuration with a tip-mounted damper.

The tip-mounted STF introduces a highly nonlinear damping force. Unlike traditional linear viscous dampers (LD), the effective viscosity of the STF increases drastically with the shear rate, making it a highly adaptive passive control mechanism. The nondimensional tip force generated by the STF is expressed as:

$$\hat{F}_{\text{STF}}(t) = \alpha_{\text{STF}} \dot{W} \hat{\eta} \left( \frac{\dot{W}}{\hat{h}} \right). \quad (1)$$

where  $\alpha_{\text{STF}}$  is the nondimensional strength index,  $\dot{W}$  is the tip velocity,  $\hat{\eta}$  is the effective viscosity, and  $\hat{h}$  is the normalized fluid gap height [2]. Previous studies have established the viability of STF dampers on purely linear beams driven by piezoelectric forces [3]. In contrast, our present work extends this foundation by explicitly comparing standard linear viscous dampers against nonlinear STF dampers in a fully nonlinear, large-deflection regime driven by base excitation.

Simulation results indicate that increasing the STF action significantly suppresses the main resonance peak, shifts it toward lower frequencies, and reduces the overall displacement across a broad frequency band. The response of an LD-supported beam (Fig. 2) shows a smooth, gradual attenuation of the primary resonance.

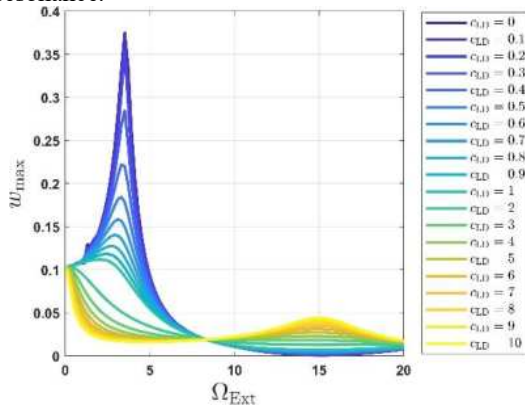


Fig. 2. Frequency response for the beam with varying linear damping ( $C_{LD}$ ).

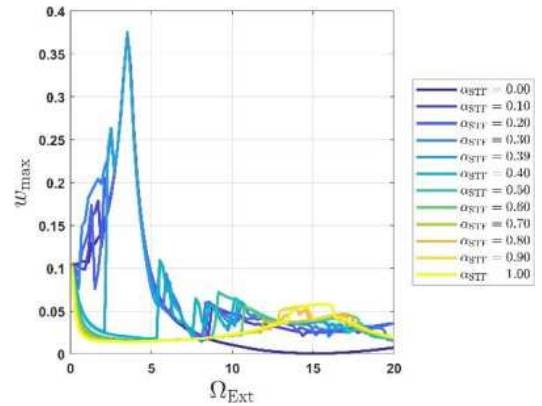


Fig. 3. Frequency response for the beam with varying  $\alpha_{STF}$  at a fixed gap height.

By comparison, the STF-supported system (Fig. 3) provides substantially stronger peak suppression at similar operational configurations. However, for moderate STF action, the response may exhibit nonsmooth characteristics and separated response branches over limited frequency ranges. This multi-valued response indicates that more than one steady vibration level can exist for the same forcing frequency. As the STF action is further strengthened, either by increasing the damping index or narrowing the fluid gap, these post-resonance irregularities smooth out, leaving only a minor high-frequency hump. Ultimately, the results highlight the normalized fluid gap as a critical design parameter, as even minor geometric adjustments can drastically alter the damping efficiency. These findings demonstrate that STF tip dampers act as highly effective, self-adaptive passive devices for mitigating resonance-driven vibrations in slender composite structures.

### Acknowledgments

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### REFERENCES

- [1] M. P. Rezaei, G. Kudra, M. Ghodsi, J. Awrejcewicz, *Overcoming stretching and shortening assumptions in Euler–Bernoulli theory using nonlinear Hencky’s beam models: Applicable to partly-shortened and partly-stretched beams*, J. Sound Vib., 589, 118807 (2025)
- [2] M. Wei, K. Lin, Q. Guo, H. Sun, *Characterization and performance analysis of a shear thickening fluid damper*, Meas. Control, 52(1-2), 72–80 (2019)
- [3] M. P. Rezaei, G. Kudra, K. Witkowski, J. Awrejcewicz, *Innovative nonlinear vibration control of beam structures using shear thickening fluid dampers*, Int. J. Non-Linear Mech., 156, 104503 (2023)