Harmonically excited capsule robot with nonlinear von Mises truss

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Abstract. This study explores the integration of a von Mises truss into a vibro-impact capsule robot, a piecewise-smooth dynamical system known for its complex coexistence of attractors, to enhance its progression speed. The research employs numerical bifurcation analysis to evaluate the effects of frequency and amplitude of the robot's driving force on its locomotion. Utilizing numerical continuation techniques within the COCO platform (Dankowicz & Schilder), we systematically compare the periodic responses of capsule robots both with and without the von Mises truss.

Introduction

Considered the capsule system shown in Fig. 1(a), which operates in bidirectional stick-slip phases according to four distinct modes: stationary capsule without impact, moving capsule without impact, stationary capsule with impact and moving capsule with impact. All these modes can be modelled via the following equations of motion

$$\begin{cases} M_{\mathrm{m}}\ddot{X}_{\mathrm{m}} &= F_{\mathrm{e}} - F_{\mathrm{i}}, \\ M_{\mathrm{c}}\ddot{X}_{\mathrm{c}} &= F_{\mathrm{f}} + F_{\mathrm{i}}, \end{cases} \tag{1}$$

where F_e is the external excitation, F_f is the friction acting on the capsule, and F_i represents the interaction

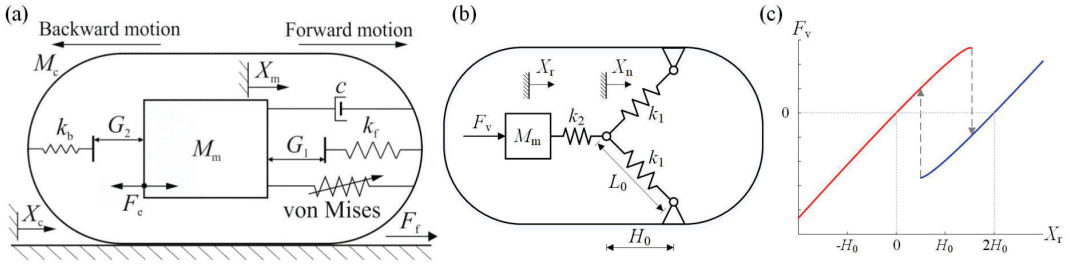

Figure 1: (a) Physical model of the vibro-impact capsule system. (b) Schematic representation of the von Mises truss. (c) Nonlinear reaction force of the von Mises truss as a function of displacement.

force between the capsule and the magnet.

Results and Discussion

Our findings (Fig. 2) reveal that incorporating the von Mises truss [1],[2] offers significant advantages when the driving force is relatively low, thereby enhancing energy efficiency. Through path-following methods, we track key periodic motions and identify an optimal operational regime within the amplitude-frequency control plane. This regime maximizes the robot's velocity for a given power consumption level, demonstrating the superior performance of the nonlinear structural configuration. Additionally, bifurcation analysis highlights that the fastest forward progression is achieved through a period-1 motion with a single right impact and no left impact.

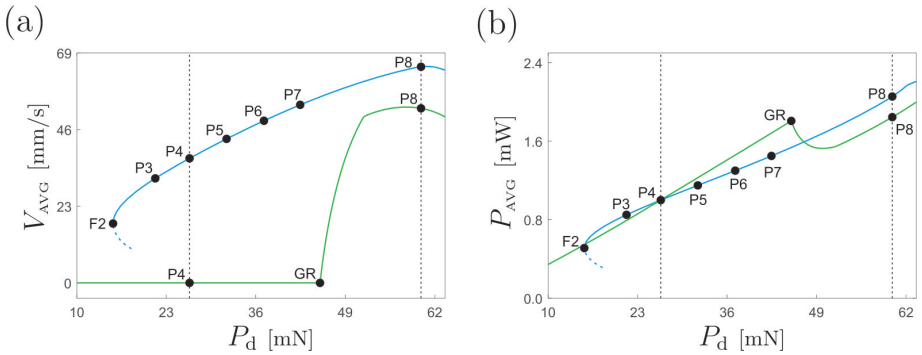

Figure 2: Continuation of the periodic response of the classical capsule system (with linear springs, in green) and capsule with von Mises spring (in blue), with respect ot excitation amplitude Pd.

References

[1] Yan, Y., Páez Chávez, J., Shen, J., Liu, Y. (2024) Dynamics of the vibro-impact capsule robot with a von Mises truss. Nonlinear Dynamics, **in press**:1-21.

[2] Falope, F. O., Pelliciari, M., Lanzoni, L., Tarantino, A. M. (2021) Snap-through and Eulerian buckling of the bi-stable von Mises truss in nonlinear elasticity: A theoretical, numerical and experimental investigation. International Journal of Non-Linear Mechanics, **134**:103739.