Flutter instability, nonholonomic constraints, and electromagnetic interactions

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We report on a recent work [1] inspired by Cazzolli et al. [2] and addressing a modification of Ziegler's double pendulum. Cazzolli et al. [2] consider a double pendulum comprising two rigid beams, joined by a hinge, and allowed to experience planar motions only. The two beams interact reciprocally through a spring and a viscous damper. At the end opposite to the hinge, one beam is connected to a wheel, which may roll without sliding on a fixed plane, and imposes that the velocity of the beam's end be orthogonal to the beam itself. The wheel, thus, realizes a nonholonomic constraint, and produces a *"follower force"* [2] parallel to the beam. The second beam is connected to a cart that translates along a fixed spatial direction under a dead load. The system undergoes flutter instability and Hopf bifurcation in certain dynamic regimes [2].

We assume the wheel to be electrically charged and exposed to an alternating electromagnetic field generated by an ideal solenoid [1]. We study the stability of the system, determine the conditions for flutter instability and bifurcations, and investigate the post-critical behavior. We also examine the role of the Lorentz force generated by the electromagnetic field, and inquire whether an effect analogous to the *Maxwell–Lodge effect* [3] is observable when the charged wheel is outside the solenoid. In our case, this effect should consist in influencing the motion of the device through the Lorentz force determined by the electric field due to the explicit time variation of the vector potential [1]. Finally, we discuss on the possible design of a micro-robot behaving as our device for biomechanical or biomedical applications.

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References

[1] A. Pastore, J. C. Harrop, D. Bigoni, A. Grillo (2026) "Dynamics of a charged Ziegler's double pendulum with a nonholonomic constraint under the joint action of a dead load and a Lorentz force", *Under review*. Available at SSRN: `http://dx.doi.org/10.2139/ssrn.6416920`.

[2] A. Cazzolli, F. Dal Corso, D. Bigoni (2020) "Non-holonomic constraints inducing flutter in stability in structures under conservative loadings", *Journal of the Mechanics and Physics of Solids*, **138**: 103919. DOI: `https://doi.org/10.1016/j.jmps.2020.103919`.

[3] G. Rousseaux, R. Kofman, O. Minazzoli (2008) "The Maxwell–Lodge effect: significance of electromagnetic potential in the classical theory", *European Physics Journal D*, **49**, 249–256.

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