Flutter, Hopf bifurcation and Ziegler paradox in structures and elastic media

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Flutter and divergence instabilities and Hopf bifurcations may occur in elastic structures subject to nonconservative loads such as follower forces and forces acting on a fixed line. This was theoretically shown by Ziegler (1956), Beck (1952), Reut (1939), among many others (see the review by Elishakoff, 2005). However, the practical realization of these nonconservative forces was considered for sixty years very difficult and often declared impossible. Koiter (1996) wrote a very direct statement on this point and proposed the “elimination of the abstraction of follower forces as external loads from the physical and engineering literature on elastic stability” and concluded with “beware of unrealistic follower forces”. In this talk we will show theoretically and experimentally how to obtain follower forces of the Ziegler type and related instabilities by exploiting Coulomb friction, a result which sheds light on the interplay between friction and flutter instability. The destabilizing effect of dissipation will be given an experimental proof [1]. We will introduce forces acting on a fixed line and explain how these can be realized to demonstrate instabilities [2]. It will finally be shown that flutter and divergence instabilities (including Hopf bifurcation and destabilizing effects connected to dissipation phenomena) can be obtained in structural systems loaded by conservative forces, as a consequence of the application of non-holonomic constraints. These constraints can be realized through a "perfect skate" (or a non-sliding wheel), or, more in general, through the slipless contact between two circular rigid cylinders, one of which is free of rotating about its axis. The motion of the structure produced by these dynamic instabilities may reach a limit cycle, a feature that can be exploited for soft robotics applications, especially for the realization of limbless locomotion [3]. Finally, the above concepts are applied to grid of structures via homogenization [4] to open an unexplored way in the design of materials working beyond hyperelasticity, in a hypoelastic context [5].

References

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