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Aerodynamische Instabilitäten dünnwandiger Strukturen zur Nutzung bei neuartigen Energy Harvestern - numerische Simulationsmethode, physikalische Effekte und analytisches Modell

Aerodynamic Instabilities of Thin-walled Structures for Use in Novel Energy Harvesters - Numerical Simulation Method, Physical Effects, and Analytical Model

Motivation

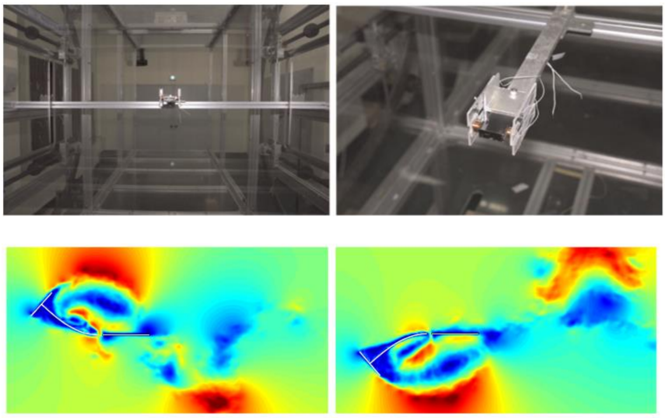
Structural systems such as long-span bridges and tall towers under wind loading may experience large amplitude vibration due to the aerodynamic phenomena like vortex-induced vibration, galloping, and flutter. In recent years, the conversion of the unstable response of thin-walled structures due to aeroelastic instabilities is a practical approach for small-scale energy harvesting. The aim is to supply sustainable green power for wireless sensor networks, portable and wireless electronic devices, especially those expected to operate for a long time with no human intervention. These structures are designed to experience large amplitude vibration at low wind speeds. These new concepts of energy harvesting are based on the conversion of mechanical vibration to electrical energy using electromagnetic and/or piezoelectric transducer. However, the transducer introduces additional electrical damping effects, which can influence the coupled aero-electromechanical response phenomena significantly. The accurate prediction of these coupled large amplitude responses is very challenging, however, necessary to investigate the mechanisms of action of the fluid-structure interaction of such and many similar structures, to quantify essential influencing parameters and, if necessary, to be able to optimize the harvester performance.

Research goal and approach

A coupled fluid-structure interaction model will be developed on Vortex Particle Methods (VPM) not only to simulate the aeroelastic response of thin-walled structures but also to evaluate and optimize the performance of aeroelastic energy harvesters. The flexible harvesters undergoing large vibrations requires a more advanced structural modeling, and therefore, a corotational finite element formulation will be coupled with VPM to account the geometrically nonlinear effects accurately. Furthermore, current developments for the modeling of atmospheric turbulence recorded in the solution area can be used to simulate the influence of wind gustiness on the structural response. The coupled method will be developed such that it can be applied, for example, to the study of lightweight roof structures. For validation of the coupled scheme, the concept of a novel electromagnetic energy harvester is to serve as a reference object. Corresponding models are tested to validate the simulation method in the wind tunnel by measuring the dynamic response of the structure in detail. The validated numerical model is then used to show that substantial aspects of harvester efficiency and structural stresses can be quantified. Finally, a new analytical model for the prediction of self-induced fluid-dynamic forces acting on thin-walled structures will be developed, which extends the concept of Scanlan Derivatives. This model should allow simplified analytical stability studies and thus serve as an alternative method for the consideration of influencing variables on the system behavior.

Innovations and outlook

The proposed novel extensions of VPM will allow the solver to be able to simulate the aeroelastic response analysis of thin-walled flexible structures and prototype harvesters. The numerically optimized harvesters can be tested in the wind tunnel experiments. Furthermore, the solver can be extended further pseudo-3D analysis of thin-walled large structures such as roofs, cooling tower, and solar chimneys.



The experimental investigation on a prototype flutter-based electromagnetic energy harvester (top), the coupled numerical analysis of the harvester (bottom)

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Project partners

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