



Some advances in the study of classical-flutter-based generators

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Abstract

This work focuses on wind-energy harvesting from two-degree-of-freedom vibrations induced by the classical-flutter instability. The main features of the system response, both at the incipient motion and during the large-amplitude limit-cycle oscillations, are discussed. The results point out some peculiar (and non-intuitive) behaviours, ruled by the still-air frequency ratio and the damping of the translational motion component, the latter simulating the operation of a conversion apparatus.

1 Introduction

Wind-energy harvesting from vibrations triggered by the classical-flutter instability considers systems that perform two-degree-of-freedom (heaving and pitching) spontaneous oscillations, without any external control of the motion.

In the perspective of outlining some design guidelines for improving the performance of flutter-based generators (Pigolotti et al., 2017a), the present work reviews some peculiar responses encountered during wide and systematic, numerical and experimental, campaigns of investigation (Pigolotti et al., 2017b,c). In particular, the effects of frequency-ratio parameter ($\gamma_n = n_{\alpha 0}/n_{\eta 0}$ pitching-to-heaving frequency ratio in still air) and ratio-to-critical heaving damping ($\xi_{\eta 0}$) are highlighted, since they play a significant role in both the critical and post-critical response of the system.

2 Methodology of investigation

Parametric numerical analyses were conducted in the frequency-domain through a linearized approach (Pigolotti et al., 2017b), using Theodorsen's model for the self-excited loads. The cut-in velocity of the device corresponds to the critical-flow speed, and high-performance systems require an as low as possible instability threshold. Therefore, the analytical model allowed to efficiently explore the influence of the governing parameters about the critical condition, so to identify a design procedure for developing potential optimal configurations.

Wind-tunnel tests were conducted at CRIACIV laboratory to investigate the post-critical response of a flat-plate sectional model (Pigolotti et al, 2017c). A specific large-amplitude setup was developed, which enabled to set the governing parameters. In particular, the linear viscous damping in the heaving component was increased (up to 18%) through eddy-current dampers, simulating the operation of an energy-conversion apparatus. Moreover, the frequency ratio was controlled by adjusting the stiffness of the heaving and/or pitching elastic suspension.

3 Main features of the response

Among all parameters describing the classical-flutter problem, the system is very sensitive to the frequency ratio γ_n . Indeed, this parameter rules the main characteristics of the motion, that is the amplitude ratio and phase difference between pitching and heaving motion components. This

behaviour was confirmed by the linear analyses, and also by the wind-tunnel experiments (Fig. 1). For low-damped configurations with γ_n lower than unity, the system is characterized by an out-of-phase motion with large heaving amplitude compared to pitching rotations, while the in-phase motion occurring for γ_n shows a motion with a marked pitching component.

Furthermore, a peculiar behaviour occurred when the heaving damping $\xi_{\eta 0}$ was increased. In particular, while the configuration with $\gamma_n < 1$ showed a reduction of the motion amplitude and a delay of the instability threshold, the configuration with $\gamma_n > 1$ exhibited a destabilizing effect of damping. Indeed, the critical condition was anticipated, and the pitching amplitudes increased while the heaving amplitudes altered slightly. These different behaviours make more similar the response of the two configurations, moving closer the amplitude ratio toward a virtual common pattern (Fig. 1a). The pitching-to-heaving phase difference also varied with a damping increment (Fig. 1b); for both values of γ_n , the configurations tend toward a quadrature-of-phase motion. Therefore, the system response seems to saturate as $\xi_{\eta 0}$ achieves high values.

Although the characteristics of the incipient motion at the instability threshold are qualitatively different from those at the limit cycle, the linear analyses returned quantitatively similar results.

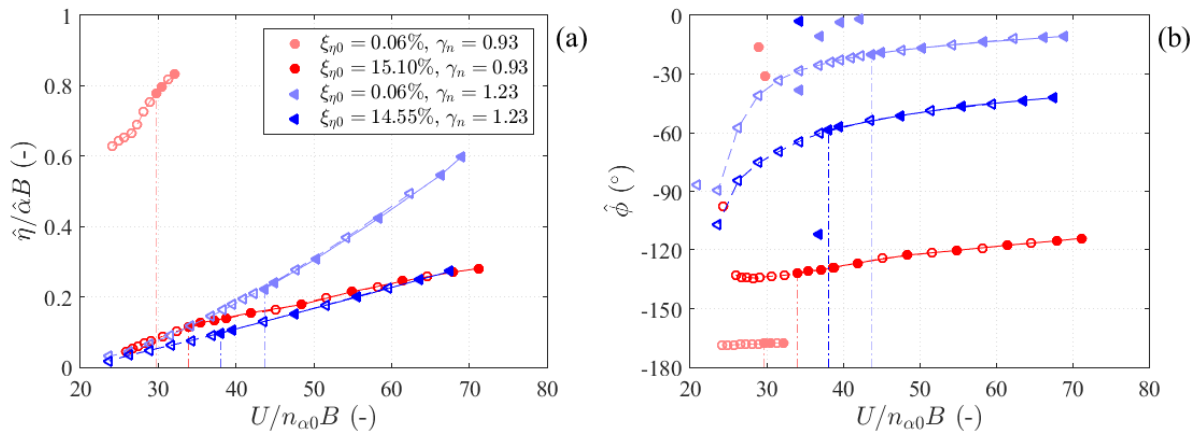


Figure 1. Amplitude ratio (a) and pitching-to-heaving phase difference (b). Vertical dash-point lines indicate the instability threshold. Filled and empty markers connected by solid and dashed lines, represents points at the limit-cycle oscillation with, respectively, increasing and decreasing flow speed (U). $n_{\alpha 0}$ is the still-air pitching frequency and B is the cross-section chord.

4 Conclusions

Classical-flutter-induced vibrations represent an effective source for wind-energy harvesting. A systematic wind-tunnel campaign, supported by parametric linear analyses, were conducted to investigate the influence of some of the governing parameters. The frequency ratio importantly rules the characteristics of the motion and the system response saturates as the heaving damping increases.

References

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