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Control of Fluid-Structure Interaction Instabilities Using Circular Cylindrical Nutation Dampers

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ABSTRACT

The paper studies damping of wind-induced instabilities, using circular cylindrical nutation dampers, through a comprehensive test program with three distinct phases. To begin with, a parametric study of the damper, in conjunction with frequency response tests, is carried out using a specially designed and instrumented Scotch-Yoke type of facility. It identifies important system variables contributing to significant energy dissipation. Results show that the optimum contributions of the system parameters can lead to an efficient damper, particularly if the operating conditions are conducive to wave-breaking. Next, visualization of the liquid sloshing modes, explaining the energy dissipation process at the fundamental level, is undertaken. It corroborates conclusions of the parametric study. Finally, wind tunnel tests with two-dimensional models substantiate, rather dramatically, the effectiveness of the nutation damper in arresting both vortex resonance and galloping-type instabilities. The damper continues to be effective even for the case when the structure is located in the wake of other structures, the situation frequently encountered in practice. A video successfully captured fluid dynamics of the damper and its effectiveness in arresting wind-induced instabilities.

NOMENCLATURE

AR : aspect ratio of floating particle, l_p/d_p
c : structural damping of wind tunnel model
c_c : system critical damping
D : mean diameter of damper, $2R$
d : sectional diameter of toroidal damper, Fig. 1
d_p : particle diameter
F_s : sloshing force
H : width of wind tunnel model
h : liquid height
L_m : length of wind tunnel model
l_p : length of particle
M : total mass of damper
M_a : added mass
M_l : liquid mass
t : time
U : nondimensional reduced wind speed, $V/\omega_n H$
V : freestream velocity
W : width of rectangular damper, Fig. 1
Y : model displacement, rms
ε_e : forced sinusoidal excitation amplitude, peak to peak
ζ_s : system damping factor, c/c_c
$\eta_{r,a}$: reduced aerodynamic damping
$\eta_{r,l}$: reduced liquid damping
ϕ : relative phase between F_s and ε_e
$\hat{\omega}_e$: nondimensional excitation frequency, ω_l/ω_e
ω_e : forced excitation frequency, rad/s
ω_l : liquid natural frequency, rad/s
ω_n : natural frequency of the structure, rad/s
ρ_a : density of the air in the wind tunnel
ρ_p : floating particles seeding density, area covered as percent of free surface

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KEY WORDS: Nutation damper, vortex resonance, galloping, vibration suppression.

INTRODUCTION

The response of aerodynamically bluff bodies when exposed to a fluid stream has been a subject of considerable study for quite some time. The prevention of fluid-elastic vibrations of marine platforms, risers, towed sonars as well as ground-based structures such as transmission lines, suspension bridges, tall buildings, etc. is of particular interest to engineers. Ever since the pioneering contribution by Strouhal, who correlated the periodicity of the

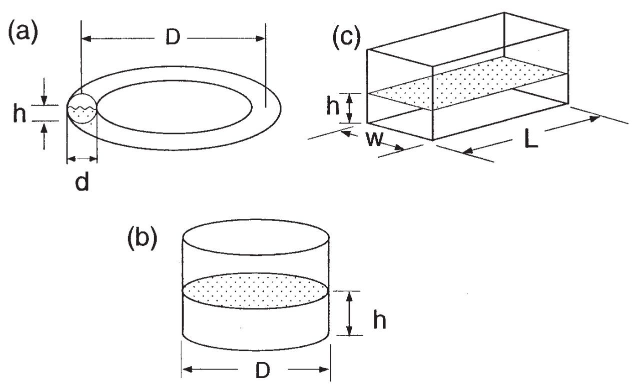

Fig. 1 Shematic diagrams showing several geometries of nutation dampers. Variety of internal devices can be used to further improve performance. In this study, focus is on circular geometry.