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Numerical study on the influence of acoustic natural frequencies on the dynamic behaviour of submerged and confined disk-like structures

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ABSTRACT

The dynamic response of disks has been deeply studied in the last years given that their dynamic characteristics present similarities with more complex disk-like structures used in real engineering applications, such as hydraulic turbine runners. Because of disk-like structures could present fatigue damage or critical failures as a result of resonance conditions, it is of paramount importance to determine their natural frequencies.

The dynamic response of disk-like structures is heavily affected by the added mass effect when they are surrounded by a heavy fluid. This added mass is greatly affected by the proximity of walls. Furthermore, the surrounding fluid cavity has its own natural frequencies and mode shapes, called acoustic natural frequencies and acoustic mode-shapes. All studies of submerged and confined disks have been carried out considering that the acoustic natural frequencies of the surrounding fluid cavity are much higher than the natural frequencies of the disk, so they do not affect each other. However, in some cases the acoustic natural frequencies are close to the natural frequencies of the submerged structure, which can be affected considerably. This case has not been deeply discussed yet.

In this paper, the influence of the acoustic natural frequencies of a cylindrical fluid cavity on the natural frequencies of a disk has been analysed numerically. First, the effect of the added mass of the fluid has been estimated when the acoustic natural frequencies of the fluid cavity are much higher than the natural frequencies of the disk. For this case, different geometrical and material parameters have been considered. Then, the parameters that affect the acoustical natural frequencies of the fluid cavity have been identified. Finally, the case with acoustic natural frequencies close to the structural natural frequencies is studied in detail and the affectation between both is discussed. All the results presented in this paper have been dimensionless in order to be used for a wide range of disk-like structures.

Therefore, with this study it is possible to identify for which conditions the dynamic response of a generic disk-like structure will be affected by the acoustic natural frequencies of its surrounding fluid cylindrical cavity.

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Nomenclature

B	Matrix of gradient components
C_f	Acoustic fluid damping matrix
C_s	Structural damping matrix
c	Speed of sound [m/s]
c_0	Maximum speed of sound [m/s]
D	Disk diameter [m]
D_{cav}	Cavity diameter [m]
$D_{cav,\,base}$	Cavity diameter (Base case). [m]
E	Young modulus [N/m^2]
F_f	Load applied on the fluid elements
F_s	Applied load vector
F_{fs}	Fluid force (Coupled system)
F_{sf}	Structure force (Coupled system)
f_{air}	Structural natural frequency in air. [Hz]
f_{cav}	Acoustic natural frequency of the cavity. [Hz]
$f_{cav,\,base}$	Acoustic natural frequency of the cavity (Base case). [Hz]
f_f	Structural natural frequency. Submerged disk. c variable. [Hz]
$f_{f,c=\infty}$	Structural natural frequency. Submerged disk. $c = \infty$. [Hz]
G	Radial gap [m]
H_{down}	Lower fluid distance [m]
H_{tot}	Cavity height [m]
H_{up}	Upper fluid distance [m]
h_D	Disk thickness [m]
i	Nodal diameters

Greek letters

λ	Correction factor (gap)
λ_{ik}	Tabulated parameter
ν	Poisson's ratio
ρ_f	Fluid density [kg/m^3]
ρ_0	Fluid density [kg/m^3]
ρ_D	Disk material density [kg/m^3]
ψ	Correction factor (Density ratio).
j	Nodal circles
k	Cross sections
K_f	Acoustic fluid stiffness matrix
K_s	Structural stiffness matrix
L	Laplacian factor
M_f	Acoustic mass matrix
M_s	Structural mass matrix
m	Slope (acoustic mode-shapes)
N_p	Element shape function for pressure
N_u	Element shape function for displacement
n	Normal vector to s
p	Dynamic fluid pressure
R	Area associated with each node (Coupled system)
r_{cav}	Cavity radius [m]
r_{int}	Interior radio [m]
s	Interface surface of the cavity
u	Nodal displacement
V	Volume
Z	Coordinate

Percentage calculations

δ (%)	Difference between simulation and theory (structural frequencies)
φ (%)	Influence of the density ratio
$\Delta_{no\ disk-disk}$ (%)	Difference between acoustic frequencies (without disk-with disk)