Engineering Analysis with Boundary Elements 81 (2017) 21–34

Contents lists available at ScienceDirect

Engineering Analysis with Boundary Elements

journal homepage: www.elsevier.com/locate/enganabound

Effects of sudden change in pitch angle on oscillating wind turbine airfoil performances

M.M. Oueslati [a,*], A.W. Dahmouni [a], S. Ben Nasrallah [b]

[a] Laboratory of Wind Energy Management and Waste Energy Recovery, Research and Technologies Center of Energy, Hammam Lif, Tunisia
[b] Laboratory of Studies of Thermal and Energy Systems, National Engineering School of Monastir, Monastir, Tunisia

ARTICLE INFO

Keywords:
Pitching airfoil
Sudden change
Aerodynamic performances
Wind turbine airfoil

ABSTRACT

In this paper, the aerodynamic performances of a wind turbine airfoil in sinusoidal pitching motion was numerically predicted and analyzed using the two-dimensional singularity method. A parametric study based on the sudden pitch angle rate variation, the reduced frequency and the pitching amplitudes have been investigated.

The results highlight the sudden change effect in pitch angle on the aerodynamic performances of the airfoil and the shedding wake. The aspect of lift and drag coefficient loops and hysteresis were customized regarding to the pure sinusoidal motion case. The dynamic stall phenomenon, which occurs during the rapid change in pitch angle, produces more drag forces influencing the wind turbines performance.

1. Introduction

Pitching airfoils have several industrial applications such as wind energy, power extraction from flapping airfoil, micro-aerial vehicle, and many other domains. Various parameters have relevant influence on the pitching airfoil performance. They can be either natural such as the wind speed and direction, the wind turbulence, the structure instabilities in the airflow, or mechanical such as the pitching amplitude, the reduced frequency of the oscillation and the oscillating motion shape. This important number of parameters encourages researchers to investigate their impact in order to optimize the system design and inhance its performance.

The oscillating motion can be a sinusoidal or a non-sinusoidal shape, which has a relevant effect on the wake and the airfoil aerodynamic performance. Literary, many numerical and experimental investigations have been conducted to study the sinusoidal oscillation motion dynamics, either in a pure pitching motion, in a pure plunging motion or in a flapping (combined pitching/plunging) motion. In fact, in flapping airfoil investigation case, Anderson et al. [1], Lai and Platzer [17], Read et al. [27], Tuncer and Platzer [29], Jones et al. [12], Young and Lai [34], Ashraf et al. [4], La Mantia and Dabnichki [19–24] have investigated the thrust and the propulsive forces generated by the airfoil and their dependence on the reduced frequency, the pitching amplitude, the camber and thickness of the airfoil.

Recently, many numerical investigations have been made to study the sinusoidal pure pitching airfoil characteristics. Amiralei et al. [3] have used the OpenFOAM software based on the finite volume discretization scheme to solve the two-dimensional Navier–Stokes equations. They have studied the influence of unsteady parameters on pitching NACA0012 airfoil at low Reynolds number between 555 and 5000. Results shown that, the maximum lift coefficient, the hysteresis loops and the generated wake were affected by those parameters. Wang et al. [30] and Gharali et al. [7] have numerically investigated the dynamic stall of a pitching airfoil using the package AnsysFluent software solving Navier–Stokes equations with kω-SST turbulence model. They have found that the kω-SST model has the capability to predict the aerodynamic loads when the dynamic stall phenomenon occurs. Moreover, this model can well capture the leading edge vortex structures generated by the airfoil during his movement. They have noticed also, that the lift coefficient under dynamic stall is more important than under the static stall. The high circulation of the leading edge vortex is the main responsible parameter of this increase.

However, the research works are limited and a few studies have been made in terms of non-sinusoidal pitching motion case. Koochesfahani [14] has experimentally studied the vortical patterns in the wake of sinusoidal and non-sinusoidal pitching airfoils. He observed the existence of an axial airflow in the cores of the wake vortices with magnitude presenting a linear dependency on the oscillation frequency and amplitude. Recently, the non-sinusoidal pitching airfoil has been used to study its effects on the thrust and the propulsion generated by a flapping foil. Hover et al. [11] have experimentally investigated the flapping airfoil perfor-

---

[*] Corresponding author
E-mail addresses: mehdi.oueslati@crten.rnrt.tn, oueslati3@yahoo.fr (M.M. Oueslati), dahmouni_anouar_wajdi@yahoo.fr (A.W. Dahmouni), Sassi.bennasrallah@enim.rnu.tn (S.B. Nasrallah).

http://dx.doi.org/10.1016/j.enganabound.2017.03.014
Received 23 February 2016; Received in revised form 5 March 2017; Accepted 14 March 2017
0955-7997/

Nomenclature

A	the airfoil surface area
a	pitch axis location with respect to the $\frac{1}{2}$ chord
c	airfoil chord length
C_T	thrust coefficient
Cp	pressure coefficient
Cl	lift coefficient
Cd	drag coefficient
C_m	moment coefficient
C_x	force coefficient at x-direction
C_y	force coefficient at y-direction
$C(k)$	Theodorsen's transfer function
d_k	the shed panel length
E_{ij}^n	normal velocity component induced at the ith panel control point by unit strength source distribution on the jth panel
E_{ij}^t	tangential velocity component induced at the ith panel control point by unit strength source distribution on the jth
$\overline{F}$	mean force applied on the airfoil in x direction
F_{ij}^n	normal velocity component induced at the ith panel control point by unit strength vorticity distribution on the jth panel
$(F_{i,N+1}^n)_k$	normal velocity component induced at the ith panel control point by unit strength vorticity distribution on the shed vorticity panel at time t_k.
F_{ij}^t	tangential velocity component induced at the ith panel control point by unit strength vorticity distribution on the jth panel
$(F_{i,N+1}^t)_k$	tangential velocity component induced at the ith panel control point by unit strength vorticity distribution on the shed vorticity panel at time t_k.
$(G_{im}^n)_k$	normal velocity component induced at the ith panel control point by unit strength mth core vortex at time t_k
$(G_{im}^t)_k$	tangential velocity component induced at the ith panel control point by unit strength mth core vortex at time t_k
$h(t)$	plunging motion function
$h0$	plunging amplitude
$\dot{h}$	velocity due to the plunging motion
$\ddot{h}$	acceleration due to the plunging motion
i	unit vectors in the airfoil-fixed coordinate system (x,y)
j	unit vectors in the airfoil-fixed coordinate system (x,y)
k	reduced frequency
l	perimeter of the airfoil
N	total airfoil panels number
p	pressure at each mid-point panel
r	distance between the jth panel and the respective mid-point of the ith panel
R_t	the pitching rate
S_t	Strouhal number
S	parametric variable
S	length of the airfoil panels
S_{sh}	length of the shed panel
S_w	length of the wake panels
tk	time step
u(t)	translation velocity at x direction
$(u_w)_k$	total velocity components in x-directions of the shed panel at the airfoil fixed coordinate system.
$V\infty$	free stream velocity
v(t)	translation velocity at y direction
V_{stream}	velocity in the fixed coordinate system
$\vec{V}$	total velocity of the airfoil
$[(V^t)_i]_k$	tangential velocities at time step t_k of the ith panel
$(v_w)_k$	total velocity components in y-directions of the shed panel at the airfoil fixed coordinate system
(x_{mi}, y_{mi})	coordinates of panel mid-point
x_m	x coordinate of mth core vortex at time t_k
y_m	y coordinate of mth core vortex at time t_k

Greek symbols

α	attack angle
β_k	the shed panel inclination
ϕ	total potential
$\phi\infty$	free stream potential
ϕS	source potential
ϕV	vortex potential
ϕW	wake potential
$(\phi_{le})_k$	disturbance potential at the airfoil leading edge
$(\phi_i)_k$	disturbance potential at the i^{th} panel control point
Γ_k	the airfoil total circulation
γ	vortex distribution strength on each airfoil panel
$(\gamma_{sh})_k$	vortex strength of shed panel
γ_w	the wake vortex strength
Ω(t)	angular velocity
ω	oscillation frequency
ρ	is the flow density
σ	source distribution strength on each airfoil panel
$\theta(t)$	pitching function
θ_0	pitching amplitude
$\dot{\theta}$	velocity due to the pitching motion
$\ddot{\theta}$	acceleration due to the pitching motion

Subscript

ε	upstream panels mid points

mance in different cases of combined pitching and plunging motions to obtain three different shapes of attack angles: a square wave, a symmetric saw tooth wave and a cosine function. They compared the obtained results with the case of ordinary attack angle. They found that the highest thrust coefficient and efficiency were obtained in the case of cosine function equal to $C_T = 0.624$ and 64%, respectively, for $\alpha_{max} = 20^\circ$ and Strouhal number $St = 0.35$. In the same context, Xiao and Liao [32] have studied numerically the effect of a cosine function attack angle obtained by the combination of pitching and plunging NACA0012 airfoil motion on the generated thrust using unsteady two-dimensional Navier–Stokes (NS) solver with a compressible flow at a low free-stream Mach number. The study was based on the variation of the Strouhal number, the maximum angle of attack and the phase angle between the plunging and pitching motions. A good efficiency and performance of the flapping airfoil were observed when they change the pitching motion from a sinusoidal function to a non-sinusoidal function composed by a cosine function and arctangent function relating the plunging velocity and the free stream velocity. To enlarge their study, Xiao et al. [33] have investigated the effects of the non-sinusoidal pitching motion on the energy extraction of an oscillating airfoil used in a bio mimic energy generator. A trapezoidal pitching motion was combined with the plunging motion to compare the obtained efficiency with that of sinusoidal pitching motion case. For that, a parametric trapezoidal function was used. It had shown that a remarkable increase in the extracted power and the total output efficiency for $S > 1$. They have mentioned also the existence of an optimal pitching profile that can be determined to obtain an output power coefficient equal to 63% and output efficiency equal to 50%. Lu et al. [15] have numerically investigated the effects of the large amplitude, the non-sinusoidal motion and the airfoil camber on the energy extracted from pitching airfoil. They applied the finite volume method using the CFD package CFX in two-dimensional incompressible flow case.