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Wind loads on heliostats and photovoltaic trackers of various aspect ratios

A. Pfahl [a,*], M. Buselmeier [b], M. Zaschke [b]

[a] German Aerospace Center (DLR), Solar Research, Pfaffenwaldring 38-40, D-70569 Stuttgart, Germany
[b] Wacker Ingenieure, Wind Engineering Consultants, Gewerbestraße 2, D-75217 Birkenfeld, Germany

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Abstract

For the layout of solar trackers the wind loads on the structure have to be known. They can be calculated by using wind load coefficients given in literature. But so far these values are only valid for aspect ratios of the panel (width to height) of about 1.0. Therefore the wind load coefficients for heliostats of aspect ratios between 0.5 and 3.0 were determined to close this gap.

As solar trackers are exposed to the turbulent atmospheric boundary layer the turbulence of the approaching flow has to be modeled. As a reliable method at reasonable cost wind tunnel measurements were chosen. Solar trackers of 30 m^2 panel size were investigated at a model scale of 1:20. Wind direction and elevation angle of the panel were varied to investigate especially the constellations at which the highest wind loads are expected (critical load cases). By spires and roughness elements a wind profile and a turbulence intensity of the modeled wind according to typical sites for solar trackers were achieved. The loads were measured by a high frequency force balance placed underneath the models. Additionally measurements of the pressure distribution on a panel with aspect ratio of 1.2 were performed to better understand the effects that lead to the peak values of the wind load coefficients.

A significant impact of the aspect ratio was measured. For the critical load cases the aspect ratio dependencies of the accordant peak wind load components were determined. By these the peak wind loads on solar trackers of varies aspect ratios can be calculated.

Regarding the single solar tracker components the main results are: Higher aspect ratios are advantageous for the dimensioning of the foundation, the pylon and the elevation drive but disadvantageous for the azimuth drive.

Keywords: Heliostat; Wind load; Aspect ratio; PV tracker; Central receiver; Solar tower plant

1. Introduction

As photovoltaic (PV) and solar thermal power plants are getting more and more important for the world wide energy supply heliostats of central receiver power plants and PV trackers are build in rising quantities. The higher the quantities the more significant is a cost effective design of the structure. For their dimensioning the wind loads are decisive and therefore should be known as precise as possible.

An important characteristic of solar trackers is the aspect ratio of the panel. At the determination of the aspect ratio two contrary aims have to be taken into account: First, to reduce the height of the solar tracker and thus the average wind speed, wide panels would be favourable. Second, to avoid long lever arms and for to reach high field densities (assuming that the distance between the solar trackers is determined by the diagonal of the panel), square panels would be best. From investigations of simple plates it is known that the aspect ratio can have a significant

* Corresponding author. Tel.: +49 711 6862 479; fax: +49 711 6862 8032.
E-mail address: Andreas.Pfahl@dlr.de (A. Pfahl).

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Nomenclature

A	mirror area (m^2)
b	width of mirror plane (m)
c	wind load coefficient (–)
$c_{F,meas,ra}$	measured wind force coefficient of aspect ratio r_a (–)
$c_{F,Pet}$	wind force coefficient according to Peterka and Derickson (1992), only for $r_a = 1$ (–)
$c_{M,meas,ra}$	measured wind moment coefficient of r_a (–)
$c_{M,Pet}$	wind moment coefficient according to Peterka and Derickson (1992), only for $r_a = 1$ (–)
c_{Py}	wind force coefficient of circular cylindrical pylon (–)
D	diameter of pylon (m)
d_{ra}	aspect ratio (r_a) dependency of peak values (– or m)
$d_{ra,F,meas}$	r_a dependency of force gained by measurements, see Table 2 (–)
$d_{ra,F,Pet}$	r_a dependency of force according to (Peterka and Derickson, 1992), see Table 2 (–)
$d_{ra,M,meas}$	r_a dependent effective lever arm of moment gained by measurements, see Table 2 (m)
$d_{ra,M,Pet}$	r_a dependent effective lever arm of moment according to (Peterka and Derickson, 1992), see Table 2 (m)
F	force caused by wind (N)
$F_{dram,ra}$	calculated wind force of aspect ratio r_a based on measurements with various r_a (N)
$F_{meas,ra}$	measured wind force of aspect ratio r_a (N)
$F_{Pet,ra}$	wind force of aspect ratio r_a according to (Peterka and Derickson, 1992) (N)
F_{ra}	wind force at certain aspect ratio (N)
F_{xPa}	horizontal wind force of panel (N)
F_{xPy}	horizontal wind force of pylon (N)
h	height of mirror plane (m)
H	height of elevation axis (m)
H_P	height of elevation axis not wind shaded by panel (m)
i	indication of x, y, Hy or z
l	characteristic lever arm (m)
M	moment caused by wind (Nm)
$M_{dram,ra}$	calculated wind moment at aspect ratio r_a based on measurements with various r_a (Nm)
$M_{meas,ra}$	measured wind moment at aspect ratio r_a (Nm)
$M_{Pet,ra}$	wind moment at aspect ratio r_a according to (Peterka and Derickson, 1992) (Nm)
M_{ra}	wind moment at certain aspect ratio (Nm)
n	exponent of power law describing wind profile (–)
p_{dyn}	dynamic pressure (N/m^2)
R	gust factor (peak wind speed/mean wind speed, for 2–3 s. gusts and 18% turbulence intensity $R = 1.6$) (–)
$r_a = b / h$	aspect ratio width to height of mirror plane (–)
v	mean wind speed at elevation axis height H (m/s)
v_{ref}	mean wind speed at mean wind tunnel height (100 cm) (m/s)
$v(z)$	mean wind speed at height z (m/s)
x	coordinate, horizontal, perpendicular to elevation axis, at base
y	coordinate, horizontal, along elevation axis, at base
z	coordinate, vertical upwards (azimuth axis); height (m)
z_{ref}	reference height (m)
α	elevation angle of mirror plane, 0° when horizontal (°)
β	wind direction, 0° when perpendicular to elevation axis (°)
ρ	density of air (kg/m^3)

influence on the wind loads (Sakamoto and Arie, 1983). For a cost effective design of solar trackers therefore the impact of their aspect ratio concerning wind loads has to be known.

Peterka and Derickson (1992) have extensively investigated the wind loads on heliostats through boundary layer wind tunnel tests. By their report the wind load coefficients for the main wind load components are available. But they explicitly remark that the tested heliostats were nearly square in shape and that the impact of the aspect ratio is not known from the tests leading to their report (p. 13). Also recent publications are based only on heliostats with aspect ratio around 1 (Wang et al., 2008; Wu et al., 2010). Therefore the aspect ratios (width/height) 0.5, 1.0, 1.2, 1.5, 2.0 and 3.0 (see Fig. 1) were investigated. Although aspect ratios of 0.5 and 3.0 are usually not chosen for solar trackers these values were investigated to achieve more pronounced results which help to clearer understand the effects that are causing the aspect ratio dependencies.

Background of the investigations is the development of a heliostat with hydraulic drive and a mirror area of 30 m^2 (HydroHelio™). Before these investigations it was not possible to decide in a profound way which aspect ratio for the mirror plane should be chosen.

For uniformity reasons the coordinate system and the characteristic lengths are according to (Peterka and Derickson, 1992, p. 11), see Fig. 2.

2. Selection of method and specifications

2.1. Selection of method

Theoretically, the wind loads could be determined at real scale heliostat models exposed to atmospheric wind.