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Experimental and theoretical study of wind loads and mechanical performance analysis of heliostats

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Abstract

Wind load greatly affects the mechanical performance and tracking accuracy of heliostats. Therefore, predicting wind loads accurately is important for developing heliostats with good performance. Quantifying an accurate wind load shape factor is the key to predict wind loads. In this paper, the wind load shape factor is obtained through measuring wind pressure distribution on the heliostat surface, and then is used to analyze the mechanical parameters of the heliostat support structure, such as stress distribution and directional deformation. The said mechanical parameters are compared with those generated by the modeled wind load which is calculated according to the related codes. The comparison results show that the theoretical method of modeling wind loads can be used to design and research the heliostat.

Keywords: Heliostat; Wind load; Mechanical performance

1. Introduction

T-shape heliostats with 100 m^2 or larger reflective areas are very sensitive to the wind load that greatly affects the mechanical performance and tracking accuracy of heliostats. Therefore, accurate prediction of the wind load is important to the structural design of the heliostat. A multitude of studies on wind load analysis for heliostats has been performed. Generally, wind tunnel test is an effective way to study wind load on the heliostat. Peterka and Derickson (1992) developed a simplified design method for defining wind loads on flat heliostats and parabolic dish collectors through wind tunnel test. The method generalized the wind load data such as the drag coefficient, lift coefficient, azimuthal moment coefficient and hinge moment coefficient. Li and Wang and their coworkers (Li and Gong, 2007; Wang et al., 2007; Gong et al., 2008, 2013; Wang et al., 2008, 2009, 2007) tested a 95 m^2 heliostat developed by the Institute of Electrical Engineering Chinese Academy of Sciences in the boundary layer wind tunnel of Hunan University. They measured the wind pressure on the reflective surface and the mechanical stresses in the pedestal for 130 cases of different wind directions and elevations. The test data yielded the static and dynamic stresses for the heliostat, the wind load shape factor and the wind flutter factor, which provided reference data for wind-resistance design of heliostats. Huss et al. (2011) developed a novel methodology for evaluating the dynamic effect of wind loads on Ivanpah LH-2 heliostats. They employed an aero-elastic heliostat model for wind tunnel test to measure the total wind forces and moments which reflect the total fluctuating forces including the background loading as well as the inertial loading. Therefore, the peak

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Nomenclature

A	reflective area of the heliostat (m^2)	u_z	wind pressure height variation factor
C_{pi}	wind pressure coefficient	v	wind velocity (m/s)
F	wind load acting on the heliostat structure (N)	ρ	air density
P_i	wind pressure on the testing surface (N/m^2)	υ	influence coefficient of wind pressure fluctuation
i	test points number	φ_z	structural vibration mode coefficient
β_z	wind flutter factor	ω_0	reference wind pressure (N/m^2)
ζ	peak wind fluctuation factor	ω_z	wind pressure (N/m^2)
u_s	wind load shape factor		

dynamic loading could be obtained. Wu et al. (2010) studied the effects of gap sizes between the facets on the wind load acting on the heliostat using the fluent software. The results showed that the wind load increased slightly with increasing gap size and the flow pattern through the gap resembled a jet flow which reduced the static pressure on the leeward surface of the facets and, consequently, increased the drag force. Zang et al. (2013) studied numerical simulation of wind velocity fluctuation on the surface of heliostats and analyzed the wind-induced dynamic response. Besides above methods, wind load test on an actual heliostat is of feasibility to analyze the structure. Sment et al. (2013) measured the boundary winds over the heliostat field and analyzed wind velocities and turbulence between rows within the field, so as to characterize and understand some differences in the impacts of dynamic wind loads on heliostat strain and cyclic fatigue between perimeter and inner-field heliostats.

This paper introduces the 100 m^2 heliostat for DAHAN solar power tower demonstration system in China and presents methods of wind load prediction and analysis of the mechanical performance of the heliostat support structure based on the wind load experiments on a full-scale heliostat.

2. Structural design and analysis of the heliostat

DAHAN solar power tower demonstration station is located at Yanqing County of Beijing, China. The heliostat field for DAHAN was built in 2009 and covers 10,000 m^2 reflective areas. The heliostat is described as below.

2.1. Introduction of the measured heliostat

Fig. 1 shows the front view and the back view of the heliostat with 100 m^2 reflective areas. The heliostat mainly consists of four parts: reflector, support structure, drive mechanism and control devices. The reflector is composed of 64 facets with the size of 1.25 m × 1.25 m. Each facet is made up of three layers: silver glass, glue and tempered glass. The facet surface is formed to curve by adjusting the bolts mounted on the back of the facet. The support structure is composed of torque tube, pedestal and the truss supporting the reflector. The truss is made of rectangular tubes with different sections. The mechanical performance of the support structure stands for the wind-resisting capabilities of heliostats.

Fig. 2 displays 100 heliostats deployed in curve form of 15 rows. The tested heliostat is located in the twelfth row and at the west edge of the field. The heliostat is marked by a red[1] circle in Fig. 2. In the flat open area that is on the west of the field and 58.7 m from the investigated heliostat, the anemometers are respectively mounted at 3.5 m, 6.5 m, 10 m and 12.5 m above the ground to characterize the wind velocities and directions approaching the heliostat from the southwest to west to northwest direction. There are no objects between the tested heliostat and the anemometers so that the wind heading to the heliostat is not blocked. Due to the approximately westerly wind approaching, the other heliostats would not affect the tested heliostat too much. In addition, 34 wind pressure sensors are symmetrically mounted on the front and back of the facets, which are marked by the red spots[2] in Fig. 1.

2.2. Mechanical performance of the heliostat

2.2.1. Theoretical method of wind load calculation

The main load acting on the heliostat is the wind loading which greatly affects the mechanical performance, optical performance and cost of the heliostat. The heliostat is a kind of low-rise structure, close to the ground, so it works in a complex wind field. Wind load on heliostats is able to be predicted using the below equations according to the standards (Ministry of Construction of People's Republic of China, 2002) for building structures:

$$F = A\omega_z \tag{1}$$

$$\omega_z = \beta_z u_s u_z \omega_0 \tag{2}$$

$$\omega_0 = \rho v^2/2 \tag{3}$$

The design values of wind speed v are determined according to the environmental conditions under which heliostat works. For DAHAN heliostat, the operational wind speed

[1] For interpretation of color in Fig. 2, the reader is referred to the web version of this article.

[2] For interpretation of color in Fig. 1, the reader is referred to the web version of this article.