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Wind pressure distribution on trough concentrator and fluctuating wind pressure characteristics

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Abstract

The distribution contours of mean wind pressure coefficient and fluctuating wind pressure coefficients on mirror surface under typical working conditions were obtained by conducting wind tunnel experiments on trough concentrator model. Meanwhile, the pattern and characteristics of wind pressure distribution on mirror surface were investigated; and the mean wind pressure coefficient distribution on mirror surface was studied. By focusing on fluctuating wind pressure characteristics, the factors influencing fluctuating wind pressure distribution were analyzed, and the power spectra of fluctuating wind pressure on some measuring taps were studied. The non-Gaussian characteristics of the fluctuating wind pressure measured on mirror surface were also assessed on the basis of kurtosis coefficient and skewness coefficient.

Keywords: Trough concentrator; Wind tunnel experiments; Wind pressure distribution; Power spectrum; Non-Gaussian characteristics

1. Introduction

Solar thermal power is a widely discussed research topic in engineering field, and trough solar power generation (shown in Fig. 1) is an internationally dominating technique with a good commercialization prospect. Since solar thermal power stations are usually located in the open, flat areas, wind load has to be properly estimated. By studying wind pressure distribution on mirror surface of heliostat and parabolic dish collectors through boundary layer wind tunnel experiment, Peterka and Derickson put forward the algorithm of wind load design on heliostat and parabolic dish collectors (Peterka et al., 1990; Peterka and Derickson, 1992). Hosoya and Peterka have conducted a series of wind tunnel tests. Their tests presented the peak load and the distribution of local pressure across the face of the solar collector (Hosoya and Peterka, 2008). The research of wind load on heliostat surface with different Reynolds numbers was done by Pfahl and Uhlemann (2011). Naeenia and Yaghoubi studied trough solar concentrator by conducting numerical simulation and wind tunnel experiments, and different wind loads on mirror surface with different pitch angles (Naeenia and Yaghoubi, 2007). Gong introduced an algorithm for wind-induced response calculation (Gong et al., 2012a). He also studied the wind load characteristics on mirror surface as well as the characteristics of wind field around a trough concentrator through on-site measurement (Gong et al., 2012b).

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Fig. 1. Trough concentrator.

The trough concentrator surface is in an arch shape, thus it can be known that the wind pressure distribution on it is complex. However, there are quite a few researches have been done for the wind pressure distribution on such structures in China. And the wind resistance design of trough concentrator in China is thus in accordance with the existing specifications or technical standard of other countries. However, due to different geographical features and climate condition, the requirements on the strength and rigidity of the concentrator group cannot be met while designed in accordance with such codes. Although there have been some advances for trough collectors in wind tunnel testing and in field measurement, there are still some limiting aspects of the measurement. Compared with previous wind tunnel test, in this paper, in order to obtain more accurate experimental data, the number of wind pressure measuring taps has been increased to 324. In addition, this paper presented the distribution of fluctuating wind pressure on mirror surface, and checked power spectrum to explain major influential factors on fluctuating wind pressure. Besides, Gaussian of wind pressure probability distribution was studied, and the paper presented non-Gaussian regions of mirror surface. And the value for the peak factor of non-Gaussian regions should take further research in future. Aiming to get a precise understanding of wind load distribution on trough concentrator surface, wind tunnel experiments on trough concentrator model were carried out in HD-3 atmospheric boundary layer wind tunnel at Hunan University in this study.

2. General information of the experiment

2.1. Experimental apparatus

The experiment was carried out in HD-3 atmospheric boundary layer wind tunnel in Wind Tunnel Laboratory of Hunan University. The wind tunnel was a straight type boundary-layer wind tunnel with low speed. The cross section of the experiment area had a width of 3 m and a height of 2.5 m, while the stable wind speed of this wind tunnel is 0.5–20 m/s. Cobra probe system was applied to measure the instantaneous wind speed. The pressure measuring apparatus was a DTCnet System. The DTCnet System has 8 modules, and each module has 64 channels, the measuring range is 0.36PSI, with accuracy ±0.05%.

2.2. Experimental model

The trough concentrator prototype consists of a mirror surface, a supporting girder, left and right fin plates, a heat collecting pipe bracket, a transmission system and pillars on both sides. The horizontal projection of mirror surface was 12.2 × 6.75 m, as shown in Fig. 2. The mirror surface consisted of 96 small mirrors with a gap of 0.02–0.05 m between them. The length scale of the trough concentrator model was 1:15 (Fig. 3). In order to measure the wind pressure on front and back mirror surface simultaneously in the pressure measuring experiment, 324 measuring taps were arranged symmetrically on both sides, with 162 taps on each. The measuring taps on front surface were arranged in a sequence from A to T, while the measuring taps on backside were arranged in the sequence of AX–TX corresponding to the taps on front surface, as shown in Fig. 4. Since the length scale was small, the gaps between small mirrors in the prototype were ignored in experimental model.

2.3. Wind field simulation and experimental conditions

The comprehensive comparison for the near-ground wind field of wind load codes between China and Europe and America (Hong and Gu, 2004) were made, including the mean velocity profile and turbulence intensity profile, fluctuating wind spectrum, etc. The mean velocity profiles of Chinese and Euro codes have a faster increase than other countries, but the mean velocity profile has little difference in the codes of different countries. Compared with other countries, the turbulence intensities in Chinese code are relatively small. For example, with terrain category B (such as the building sparse open country, suburb, forests) and at the height of 10 m, the turbulence intensity value of Chinese code is 0.12, the minimum value of the other countries is 0.19, and the maximum value is 0.26.

Based on the terrain roughness characteristics of the site where the trough concentrator is located, the spire-roughness technique was used to simulate the atmospheric boundary layer wind field in wind tunnel according to international experiment method (Yukio, 2009) and current Chinese Code on terrain category B (Load Code for the Design of Building Structures, 2012). Wind velocity profile is expressed by Eq. (1):

$$V_z = V_b\left(\frac{Z}{Z_b}\right)^{\alpha} \tag{1}$$

where Z_b is the standard reference height; V_b is the mean wind speed at the standard reference height; Z is the height above ground; V_z is the wind speed at the height Z; α is the surface roughness index. The experiment in this study is to