Experimental Research on Influencing Factors of Surface Friction Coefficient of Solar PV Panels

Zhang Dan, Zhao Mingzhi

1School of Energy and Power Engineering, Inner Mongolia University of Technology, Hohhot, China 010051.
2China General Certification Center, Beijing, China 100000

11078745247@qq.com, 2zhaomingzhi2020@163.com

Abstract: This paper analyzes the friction force model of dust on the solar panel. By using the weight of the solar panel on the solar panel, we can find out the angle that can best adapt to the sliding of dust by changing the angle of the solar panel. Coefficient of friction between the panels. The results show that the coefficient of sliding friction decreases with the increase of dust particle size.

Key words: dust; solar panels; coefficient of friction

1.Introduction

As countries pay more and more attention to the development of energy and environment, the proportion of traditional energy in energy consumption due to high pollution and high energy consumption will be smaller and smaller. As a renewable, non-polluting energy source, solar energy will grow rapidly. However, there will be some problems in the development of PV power plants, such as the problem of sand accumulation on PV panels. Its impact on the panel has gradually become a hot spot. As the dust slides down the panel, the sliding friction on the surface creates a drag. It can be seen that the friction coefficient of sand and dust affects the research of sediment accumulation to a certain extent on PV panels.

Many scholars at home and abroad to analyze the friction. Based on a swash plate slider in a hydraulic axial piston pump, W Shi [1] developed a rotational model using molecular dynamics to study the frictional properties of atoms. C Chen et al. [2] used molecular dynamics simulations to determine the effects of different temperatures on the dynamic friction properties of Cu substrates in single crystal and polycrystalline structures. The domestic research on the friction between dust and solar panels is relatively rare. Hu Lin et al. [3] studied the friction caused by the interaction between the rod and the particulate matter. DH Cho [4] and so on nanoscale friction and wear were studied. Wang Yazhen [5] studied the influence of the surface morphology on the friction force and established the friction model of the nano rough surface and the atomic smooth surface.

Although there are many researches on friction at home and abroad, there are few studies on the dust on solar panels. This paper focuses on the analysis of friction. Through the experiment, the variation law of the coefficient of sliding friction was obtained, and the main influencing factors were found out. By comparing the coefficient of friction between the dry and wet solar panels, the correlation between them was found out.
2. Friction Analysis of Sand Particles on Horizontal Panels

2.1 Sliding friction adhesion friction theory

2.1.1 The friction surface is plastic contact. The actual contact area is only a very small part. When the load acts on the contact, the stress on the contact point reaches the yield limit of compression and plastic deformation will occur. Thereafter, the stress will not change and the load will continue to increase by increasing the contact area.

2.1.2 Sliding friction is the process of jumping. The contact points are in a plastic flow state, and when the contact points slide, the contact points instantaneously generate high temperature, thus causing the two objects to stick together. The adhesion points have the adhesive force. Under the action of the friction force, the shear point at the adhesion point slides and the sliding friction is accompanied by the formation of sticky point and shear process.

2.1.3 Friction is the sum of the resistance caused by the sticking effect and furrow effect

\[ F = T + P_e = A \tau_b + S \rho_e \]  

In the formula, \( T \) is the shear force, \( f \) is the furrow force, \( A \) is the adhesion area, \( \tau \) the actual contact area, the shear strength at the adhesion point, \( S \) is the furrow area, and \( \rho \) is the furrow force per unit area. Experiments show that the size is related to the sliding speed and lubrication state and is close to the shear strength limit of the soft material, which indicates that the shear occurs inside the soft material and causes the phenomenon of material migration. It is proportional to the yield point of the soft material and not to the lubrication state, and the depth of embedment decreases as the yield point of the soft material increases.

2.2 Sand particles in the horizontal panel on the friction force model

In order to predict the sliding resistance of dust on solar panels, the dust is first reduced to spherical particles, the cross-section of the ball over the center of the sphere is a cylinder with a width of 1, which is convenient for stress analysis. Figure 1 shows a simplified sand particle-solar panel interaction model. Assuming that the force of the solar panels on the dust particle size is in the radial direction, the resultant force in the horizontal and vertical directions can be written as:

\[ R = \int_{0}^{\theta_0} \sigma r \sin \theta \, d\theta \]

\[ W = \int_{0}^{\theta_0} \sigma r \cos \theta \, d\theta \]  

In the above formula, \( R \) is the sliding friction; \( W \) is the vertical load, that is, the wind load; \( \sigma \) is the normal stress; \( r \) is the radius of the wheel; \( \theta \) is the contact angle;

![Figure 1. Simplified dust particle-solar panel interaction model](image)

Assuming that the radial pressure \( \sigma \) acting on the dust edge is the normal pressure-settlement relationship under the tempered glass plane of the solar panel at the same depth [6]

\[ \sigma = p = (k_c + k_q)z^n \]  

(3)
In the formula, and are respectively tempered glass cohesion and frictional deformation modulus; \( n \) is the subsidence modulus.

The formula (3), and into (2) the first formula and points were:

\[
R = \left( \frac{2^n}{n+1} \right) (k_a + k_\phi) \tag{4}
\]

Available from Figure 2.9 \( x^2 = D - (z_0 - z) \)(\( z_0 - z \))

When the amount of subsidence is small \( x^2 \approx D(z_0 - z) \)

\[
W = \left( k_a + k_\phi \right) \int_0^{z_0} \left( \frac{z}{\sqrt{D}} \right)^n dz \tag{6}
\]

other \( z_0 - z = t^2 \), then \( dz = -2t \, dt \), into (6) Got it

\[
w = \left( k_a + k_\phi \right) \sqrt{D} \int_0^{z_0} (z_0 - t^2)^n dt \tag{7}
\]

Expand the \( (z_0 - t^2)^n \), only take the first two items, the amount of solar panels available after settlement

\[
z_0 = \left[ \frac{3W}{\sqrt{D}(3-n)} \right]^{2/(2n+1)} \tag{8}
\]

Substituting equation (4) in Eq. (8), we get sliding friction R

\[
R = \left[ \left( \frac{3W}{\sqrt{D}} \right)^{2n+2} \frac{2n+2}{(3-n)^{2n+2} (n-1)^{2n+1} n (k_a + k_\phi) (3W)^{2n+2}} \right]^{1/(2n+1)} \tag{9}
\]

In order to study the force and force of sand under the same area under wind load and different particle sizes under load, a certain amount of pressure, \( F \), between the planks and the solar panels under a certain area of the planks of \( S \) is assumed to be Layers of dust particles loosely arranged, dust particles is a regular ball, as shown in Figure 2:

**Figure 2.** Single layer dust particles placed between the plank and the ground

**Figure 3.** Single-layer dust particles in the solar panel surface arrangement diagram

It is assumed that the dust particles are the most loosely arranged on the solar panel [7], as shown in Figure 3. The total number of dust particles is \( N \), then:

\[
N = \frac{S}{D^2} \tag{10}
\]

The vertical load on each dust particle is:

\[
W = \frac{F}{N} = \frac{FD^2}{S} \tag{11}
\]

Substituting (11) into (9) gives the sliding friction force R as:

\[
R = \left[ \left( \frac{2n+2}{(3-n)^{2n+2} (n-1)^{2n+1} n (k_a + k_\phi) (3F)^{2n+2} D^{3n+3}} \right) \right]^{1/(2n+1)} \tag{12}
\]
By \( R = \frac{4}{3} \pi D^3 \rho g f \), got it:

\[
f = \frac{3}{4 \pi \rho g D^3} \left[ \frac{S^{2n+2}}{(3-n)^{2n+2}(n-1)^{2n+1}n(k_s+k_d)(3F)^{2n+2}D^{2n+3}} \right]^{1/2n+1} \tag{13}
\]

In the formula, the density of dust particles. From (13), we can see that when the diameter of dust particles increases, the sliding friction coefficient \( f \) decreases.

3.Dust on the sloping panels friction coefficient of variation of sliding law

3.1 Experimental Preparation

Solar panels will be affected by the wind load, meanwhile, the dust on the solar panels will also be affected by the wind load during the sliding process. The wind load equation [8] of the solar panel is as follows:

\[
W = 0.5 C_w \rho V_{\text{max}}^2 S \alpha I J
\tag{14}
\]

Where: wind coefficient, take 0.65 +0.009 theta; \( \theta \) is the angle between the solar panel and the ground to take 90 degrees; for the air density to take 1.225; for the maximum wind speed to take 30; \( S \) solar panels to take the area Solar panels are made of wood with an area of 0.0036; \( I \) is a factor of 1; \( \alpha \) is a height correction factor of 1.631; \( J \) is an environment factor of 1.15. \( W \) is a maximum of 5.434N, as long as the force applied to the panel is less than this value. In line with the experimental conditions, in the following analysis, the pressure generated by the weight of the wood instead of solar panels suffered wind load.

The tilt angle of the solar panel bracket is set to \( 0^\circ \), \( 15^\circ \), \( 30^\circ \), \( 45^\circ \), \( 60^\circ \), \( 75^\circ \), placed on the solar panels wooden block size of \( 6 \times 6 \times 2cm \), the dust particles adhere to one side of the block, the adhesion of sand Dust particles face and solar panels close together with a dynamometer slow and uniform pulling wood, and record the dynamometer data, as shown in Figure 4 and Figure 5:

\[\text{Figure 4. Solar panels with different angles of inclination}\]
In order to obtain a more accurate coefficient of friction, measured four times at each angle, the first dynamometer pulls only one block of wood, after each test to add a block of wood, up to four until each sliding friction coefficient, And then take the average is the sliding friction coefficient of this angle.

As dust and wood stick together, the force analysis can be regarded as a whole, the weight of the wood along the slope of the solar panel component of the size of the force of friction with the sand the same size, wood Gravity perpendicular to the slope of the solar panel component of the size of the wind load the same size. Wind load here is mainly referring to the pressure resistance, friction resistance is much smaller than the pressure resistance, will not be considered. Thus, the formula for calculating the coefficient of sliding friction between sand and solar panels is obtained as follows:

\[
f = \frac{F - mg \sin \theta}{mg \cos \theta}
\]

Where \( f \) is the coefficient of sliding friction between sand and solar panels; \( F \) is the reading of the tensioner, that is, the tension; \( m \) is the mass of the block; \( \theta \) is the inclination of the solar panel; \( g \) is the acceleration of gravity, take \( 9.8 \text{ m/s}^2 \).

### 3.2 Dust on the dry solar panels coefficient of variation of friction

In order to obtain the variation law of the friction coefficient of dust particles on the solar panel, the range of 0.07 ~ 0.08, 0.08 ~ 0.09, 0.09 ~ 0.1, 0.1 ~ 0.2, 0.2 ~ 0.3 was selected in the dust, In the experiment, the sliding friction coefficients measured by different numbers of wood blocks are averaged, and then the sliding friction coefficients obtained from different six angles are averaged. The friction coefficient varies with the particle size of dust Figure 6 shows:

![Figure 6. Sliding friction coefficient with the size of dust particle size changes](image)

As can be seen from the figure, the sliding friction coefficient tends to decrease as the particle size becomes larger, and the correlation coefficient between the sliding friction coefficient and the size of the particles is obtained. The correlation coefficient between them is 0.804, indicating that the particle size The size of the coefficient of sliding friction has a certain ability to explain. In less than 0.1mm, the change is relatively stable, basically unchanged; more than 0.1mm, the change is relatively larger. This is part of the reason why the coefficient of friction changes slowly and slowly.
When the dip angle of solar panels changes, each dip angle averages the friction coefficient for different dust particle ranges and loads, and the sliding friction coefficient between dust and solar panels also changes, as shown in Fig. 7:

![Figure 7. Sliding Friction Varies with Solar Panel Tilt](image)

The coefficient of sliding friction between sand and solar panels is minimized at this angle of inclination as the angle of inclination of the solar panel closely follows the slip of dust particles. It can be seen from Figure 4.10 that the solar panel has a dip angle of about 15°. For the dust in different places, the physical and chemical properties of its surface are different, the surface topography is also different. Different solar panels, the surface is also different, so this dip is random and accidental.

4 Conclusion

Through experiments, changing the angle of solar panels and the wind load, we can get the rule that the sliding friction coefficient decreases with the dust particle size increasing, which is mainly caused by the decrease of the adhesion effect. From the perspective of changing solar panels, when the dust particle size is relatively small, the friction coefficient tends to increase with the increase of load. It can not be determined which role plays a leading role. When the particle size increases, the coefficient of sliding friction increases with the increase of load decreasing trend. Through the solar panel inclination changes, the coefficient of sliding friction coefficient at the minimum when the inclination of about 15°, at this angle most can adapt to the sliding of dust.

References

[1] Shi W, Luo X, Zhang Z, et al. Influence of external load on the frictional characteristics of rotary model using a molecular dynamics approach [J]. Computational Materials Science, 2016, 122: 201-209

[2] Chien C, Wang C, Tsai C, et al. Temperature effect on kinetic friction characteristics of Cu substrate composed by single crystal and polycrystalline structures [J]. Computational Materials Science, 2016, 117: 412-421

[3] HU Lin, YANG Ping, XU Ting et al. Static Friction on Round Rods in Particulate Matter [J]. Acta Physica Sinica, 2003, 52 (4): 879-882

[4] Cho D. H, Bhushan B, Nanofriction and nanowear of polypropylene, polyethylene terephthalate, and high-density polyethylene during sliding [J]. Wear, 2016, s352-353: 18-23

[5] WANG Ya-Zhen, HUANG Ping. Calculation of Microscopic Sliding Friction on Nanoscale Stochastic Rough Surface [J]. Acta Physica Sinica, 2013, 62 (10): 106801-106801

[6] Huang Zuyong. Principles of ground vehicles [M]. Beijing: Mechanical Industry Press, 1985

[7] Li Guangxin. Soil mechanics [M]. Beijing: Tsinghua University Press, 2013
[8] Zhang Qizhu, Liu Zhizhang, Qi Xiaohui, et al. Analysis of wind load on solar PV panels [J]. Energy Technology, 2010, 31 (2): 93-95