Adsorption Structure Analysis of Photovoltaic Cleaning Robot Based on Negative Pressure Adsorption

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Abstract: In recent years, with the energy consumption and the rapid development of photovoltaic power generation, the task of photovoltaic panel cleaning is particularly heavy.In this paper, for the cleaning of photovoltaic panels, an adsorption structure based on vacuum suction robot is established. Adopting the negative pressure technology to design and test the robot's adsorption mechanism, the main factors affecting the adsorption capacity of the robot, such as effective pumping speed and leakage, are analyzed.After the ansysis,we got the negative pressure response curve in the sucker.Through theoretical and experimental analysis of the leakage rate of the sucker structure, it provides an intuitive and effective way for the analysis of the adsorption performance of the vacuum system and the design of the adsorption device.

Key Words: Photovoltaic , Negative pressure adsorption, Robot, Sucker

1 INTRODUCTION

In the research of photovoltaic power generation system, the deposition of fine particles such as dust and dust of photovoltaic panels needs to be cleaned regularly on the surface of photovoltaic pane ls [1-3]. Currently, various types of cleaning methods are introduced at home and abroad, such as manual and mechanical cleaning. It needs labor-intensive for cleaning; large-scale cleaning device has poor mobility . The use of clean robot operations will greatly reduce cleaning costs, improve the working environment for workers and improve labor productivity, which has considerable social, economic significance and broad application prospects. In this dissertation, the cross-platform robot platform is taken as the core to study the vacuum adsorption system , and it focuses on the selection, structure and performance of the adsorption system.

2 VACUUM ADSORPTION SYSTEM

Climbing robot adsorption mainly includes biomimetic adsorption, vacuum adsorption, rotor adsorption, magnetic adsorption and vibration adsorption and so on [4-11]. The vacuum adsorption method has the advantages of simple structure, strong load capacity and stable adsorption force. However, due to the limitation of its own structure, the vacuum adsorption method has some shortcomings such as excessive wall flatness, excessive vacuum generation device, and too-simple body movement in early applications. In the previous studies on the wall-mounted robot vacuum adsorption system, most of them focus on the application and development of adsorption technology, and the research on their mechanism and the research methods of dynamic adsorption properties are still inadequate. Among the robot systems, the vacuum adsorption system is one of the most important technologies. The vacuum adsorption system has the characteristics of light weight, small volume, compact structure and high reliability. It is one of the key technologies of the wall cleaning robot [12]. Vacuum suction systems of common wall-climbing robots are all multi-sucker group structures. In this paper, a basic structure design of a multi-sucker-wall group climbing wall robot is carried out and the vacuum adsorption system is further studied.

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2.1 Composition of adsorption mechanism and system

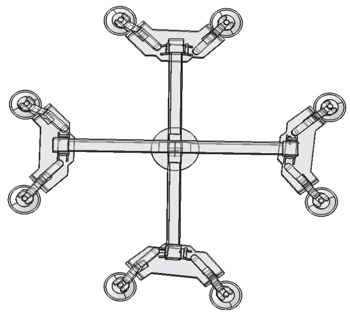

Fig. 1 adsorption structure

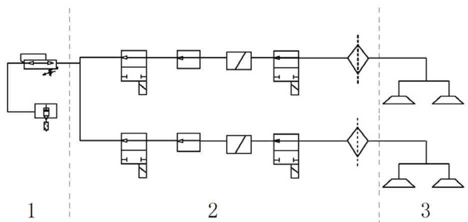

Fig. 2 gas path principle of vacuum adsorption system

Adsorption structure of the vacuum adsorption system is shown in Figure 1, and the climbing robot uses a cross structure in which two sets of sucker were installed in the upper and lower framework.The sucker can be driven vertically by the motor mobile.The rail and the rotating mechanism are installed between internal and external framework, and alternating adsorption of suction cups allows the body to move forward, turn the obstacle and other movements.

Gas suction system is shown in Figure 2, and it mainly consists of 1, 2, 3 and 3 parts of the pipeline. Part 1 is a vacuum generating part, in which the miniature vacuum pump provides power for the adsorption device, and the muffler reduces the working noise of the vacuum pump. Part 2 is the vacuum control part, the solenoid valve control gas on-off, the vacuum filter used to filter the entire pipeline of impurities to protect the vacuum assembly, one-way valve uses to prevent vacuum leaks, negative pressure switch feedback vacuum pressure. as a vacuum negative Feedback device, the suction cup suction when the pressure is less than the value of the negative pressure switch automatically start the vacuum pump. Part 3 is a sucker, the end of the adsorption system as the adsorption actuator.

Throughout the vacuum adsorption system, the vacuum pump through the exhaust operation, the suction cup and the air in the pipeline to form a pressure difference inside and outside the suction cup, so that the suction cup can be adsorbed on the wall.

2.2 Adsorption performance of vacuum adsorption system

The adsorption capacity of an adsorption system with n suction cups is calculated as :

$$W = \sum_{i=1}^{n} (p_0 - p_i) * \pi r_i^2 * \eta \qquad (1)$$

Where: W is the adsorption force, N ; p_0 is the standard atmospheric pressure value, kpa ; p_i is the vacuum degree (relative pressure) in the suction cup after extraction, kpa ; r_i is the effective radius of the suction cup in mm . η is the safety factor.

By (1), we can find that the suction of the adsorption system is the resultant of suction of each suction cup in the suction cup group. Where n and r_i can roughly be the total effective adsorption area of the adsorption device[13].

Vacuum adsorption system is essentially a vacuum suction cup sucker, and vacuum pump adsorption system as a power extraction system. Simplified vacuum adsorption system shown in Figure 3. Vacuum pumping speed curve shown in Figure 4.

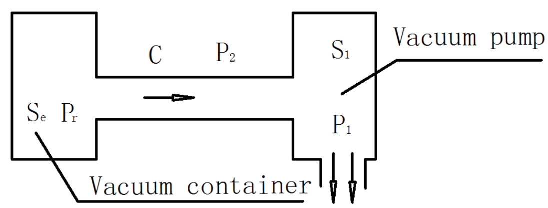

Fig. 3 vacuum adsorption system

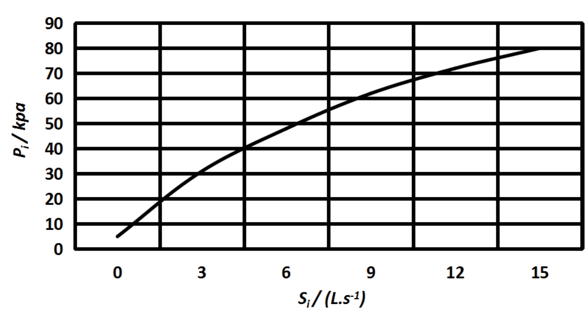

Fig.4 suction curve of vacuum pump

Figure 3: S_1 for the vacuum pump inlet pumping speed; p_1 vacuum pump inlet pressure; c for the pipeline conductance; p_2 for the pipeline pressure; S_e effective pumping speed; p_1 for the suction cup vacuum.

Assuming that the desorption of gas and the avoidance of permeation of the container are not considered, and the gas temperature is at room temperature, the dynamic equation of the suction is [14]:

$$V\frac{\mathrm{dp}}{dt} = -p_i S_e + Q_l \tag{2}$$

Where: V is the volume of the container; Q_l is the amount of gas leakage per unit time. $\mathrm{dp}/dt = 0$ is available when the system eventually reaches a steady state:

$$p_i S_e = Q_l \tag{3}$$

Through the above formula can be found, the vacuum suction system is a dynamic equilibrium process, the ultimate stability of the vacuum within the container P_i depends on the effective pumping speed S_e and the container leakage Q_l.

2. 3 Effective pumping velocity of vacuum adsorption system

Effective pumping speed reflects the vacuum system of the exhaust capacity, the final system can determine the stability of the pressure. But in a vacuum adsorption system, the effective pumping speed is not a constant, and not by the vacuum pump alone. According to the principle of constant flow can be obtained [14]:

$$S_1 p_1 = C(p_i - p_1) = S_e p_i \tag{4}$$

Available by calculation:

$$S_e = \frac{C}{1+\frac{C}{S_1}} = \frac{S_1}{1+\frac{S_1}{C}} \tag{5}$$

Because $C > 0$、$S_1 > 0$, available :

$$S_e < C \quad \text{and} \quad S_e < S_1 \tag{6}$$

Through the above deduction, we can see that without considering the leakage and other performance indicators, the effective pumping speed suction cup is not only related to the performance of the vacuum pump, and the conductance of the pipeline, simply increase the vacuum pump ultimate pressure and flow does not increase Adsorption system performance. Use short and thick pipe with high performance vacuum pump can make the system performance effectively.

2. 4 Study on sucker performance of adsorption system

The sucker is the actuator of the sorption device, the suction between the sucker and the wall, and the vacuum leak rate between the two determine the performance of the system and the sucker has a significant effect on the sorption structure. In the previous studies, the sucker was difficult to quantitatively analyze due to the severe deformation of the sucker during the whole adsorption process, the difficulty of calculating the precise size data and the different degree of sealing of the sucker on the adsorption surfaces of different materials .

In order to study the influence of pressure on the leakage rate, assuming that the room temperature is constant and the inlet pressure is atmospheric pressure, it means that the leak rate of the leak hole under a certain pressure is [15] :

$$Q = k \cdot \Delta p^n \tag{7}$$

Where: Q is the leak rate of the leak hole; Δp is the suction cup pressure; k and n are the undetermined coefficients of the leak hole.

In this paper, the model of gas in sucker is established by using fluid dynamics. Figures 5 and 6 show the simulated state of the suction cup and the adsorption state curve.

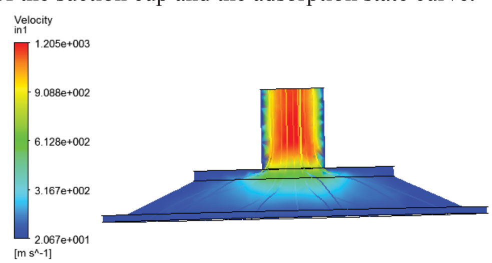

Figure 5 analog state display diagram

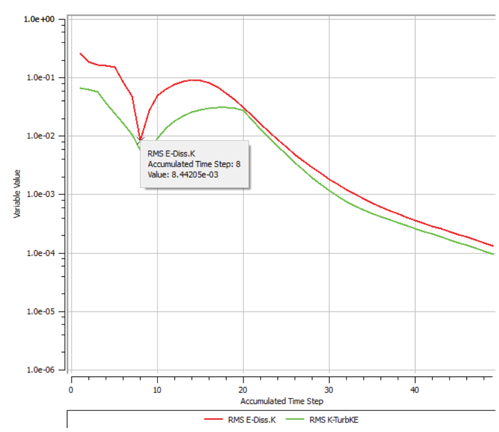

Figure 6 Suction cup adsorption state curve

It can be seen from Figures 5 and 6 that the negative pressure value of the sucker satisfies the analysis of the adsorption reliability under the static state.

3 ADSORPTION SWITCHING ANALYSIS OF VACUUM ADSORPTION SYSTEM

Vacuum adsorption robot take the action of multi-sucker group switching strategy. The switch of dynamic adsorption will inevitably lead to the vacuum fluctuation of the vacuum adsorption system and increase the instability of the system. Therefore, in addition to the static adsorption part of the vacuum adsorption system, the dynamic switching process is also the focus of study.

3. 1 Adsorption and release of vacuum adsorption system

Vacuum adsorption system from the start to the vacuum inside the suction cup takes a certain amount of time, and after the release of the suction cup there will be a certain period of time to maintain the vacuum. If the sucker group adsorption time is too long, sucker group release time is too short, it may cause the system instantaneous pressure loss, causing overturning or slipping. Suppose the volume of the suction cup v_0, according to the model in Figure 3 shows that within a unit of time dt pumping ΔQ is:

$$\Delta Q = p_i S_e dt - Q_l dt \tag{8}$$

According to the gas inside the suction cup and the relationship between the pressure available:

$$\frac{p_i V_0 - \Delta Q}{V_0} = p_i - dp_i \tag{9}$$

Since S_e has nothing to do with p_i and t, temporarily set as a constant. In pumping too much Most of the time the exhaust volume is much larger than the leakage, so temporarily Consider leakage. Substituting (8) into (9) and integrating it :

$$t = \frac{V_0}{S_e} \lg \frac{p_0}{p_i} \tag{10}$$

Where: p_0 is initial pressure for $t = 0$ when the suction cup vacuum, that is, the standard atmospheric pressure. According to equation (5) available :

$$t_{\text{in}} = V_0 \left(\frac{1}{C} + \frac{1}{S_1}\right) \lg \frac{p_0}{p_i} \tag{11}$$

From (8) we can see, in the same volume of the suction cup V_0, the vacuum suction system depends mainly on the exhaust time vacuum pumping speed S_e.

Sucker release process is known:

$$\Delta Q = Q_l dt \tag{12}$$

In the same way, formulas (7) and (9)are available:

$$dt = \frac{V_0}{k(p_0 - p_i)^n} dp_i \tag{13}$$

The formula (13) points available:

$$t_{\text{out}} = \frac{V_0 (p_0 - p_i)^{1-n}}{k(n-1)} \tag{14}$$

According to equation (14), it can be found that the bigger the k and n are, the shorter the releasing time of the sucker, that is, the bigger the leakage rate is, the shorter the sucking time is.

3. 2 Anti overturning ability of sucker group

Many factors affect the suction cup group, such as the diameter of the suction cup, the arrangement of the suction cup and the distance between the suction cup, etc. Where in the increase of the diameter and the spacing can improve the anti-overturning ability.

The improvement is due to the reduction of the anti overturning ability of the sucker group. Due to the angle between the photovoltaic plate and the vertical direction, according to the structure of the suction cup set shown in Fig.7 a), the Y structure of the cross is taken as an example to analyze the overturning force.

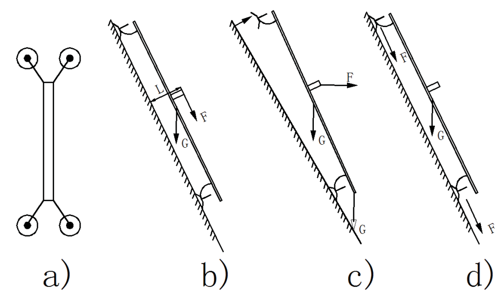

Figure 7 Analysis of overturning force in Y direction of sucker group

As shown in Fig. 7 b) - d), the axial deformation of the sucker group will be deformed under the maximum load in the suction cup group. In order to ensure the stability of the system, the shaft is modeled and analyzed by finite element analysis, Simulation results and data shown in Figure 8, Table 1 below.

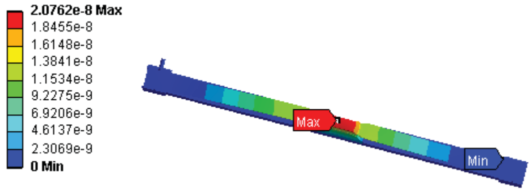

Figure 8 analog state display diagram

Table 1.Experimental simulation data sheet

Strength coefficient (Pa)	9.2e+008
Strength Exponent	-0.106
Ductility Coefficient	0.213
Ductility Exponent	-0.47
Young's Modulus(Pa)	2.e+011
Poisson's Ratio	0.3
Bulk Modulus(Pa)	1.6667e+011
Shear Modulus (Pa)	7.6923e+010
Compressive Yield Strength (Pa)	2.5e+008
Tensile Ultimate Strength(Pa)	4.6e+008

It can be seen from the data in Fig. 8 and Fig. 1 that the adsorption method can be found to be safer and more effective when considering the adsorption capacity of the vacuum adsorption system without considering other factors of the robot body.

4 CONCLUSION

Based on the above principle and design, this paper chooses a reasonable structure of the sucker, analyzes the sucker of the photovoltaic cleaning robot in the X and Y directions of photovoltaic cleaning robot was analyzed, and proves that the adsorption system has the advantages of reliable adsorption and adaptability to the adsorption surface, The above experimental analysis，which provides a direction for further improvement and improvement of the robot adsorption scheme. It has laid a certain theoretical foundation for the research and application of photovoltaic clean robot.

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