Characteristics and design key points of small CIGS solar UAV

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Abstract. Based on the working mode of small CIGS solar UAV, the difference and basic characteristics between its energy power system and traditional UAV are analyzed. Some key problems to be solved in the miniaturization design of flight platform are studied from airfoil selection, aerodynamic layout design and basic parameter calculation. By increasing the power factor of the airfoil and reducing the wing load, the UAV can get a smaller sinking rate. In addition, through the coupling of energy system and power system and the use of new composite materials, the overall efficiency can also be improved and the endurance of solar UAV can be effectively extended. Combined with the intelligent flight control system, it can realize full autonomous over the horizon long-time flight. The main conclusions can provide reference for the miniaturization design and optimization of solar UAV.

1. Introduction

Compared with UAVs using traditional energy, solar UAVs have the advantages of long endurance, large coverage, strong environmental adaptability and simple maintenance, which are suitable for performing normal patrol, signal relay and other tasks. Therefore, solar UAVs show more and more important value in military and civil fields[1]. Large-scale high altitude long endurance solar UAV is designed to fly near space, which has certain limitations in the industry application. However, the small solar UAV does not need to meet the requirements of high altitude and cross night flight, so solar energy can be used as a supplementary energy. According to the basic working characteristics of the small CIGS solar UAV, this paper further analyzes some key issues in the overall design, so as to improve the working efficiency of the UAV system.

2. Basic characteristics of energy and power system

2.1. Energy system

According to the structure and materials, solar cells are divided into different categories. Among the crystalline silicon series solar cells, the monocrystalline silicon solar cell is the earliest, with relatively mature manufacturing process. It is the solar cell with the highest conversion rate in the industrial development. The conversion efficiency of polycrystalline silicon solar cell is slightly lower than that of monocrystalline silicon solar cell, both of which have poor deformation resistance and are easy to
break, so the substrate is generally rigid. Once bending occurs, it will lead to crystal fragmentation, damage the solar cell structure, and cause short circuit and failure. With the continuous development of solar cell technology, high efficiency and thin film technology are becoming more and more mature. As the most important photovoltaic conversion unit in solar UAV, it not only has high conversion efficiency, but also has high reliability and economic performance. Table 1 shows the comparison of several common solar cell performance parameters.

Table 1. Comparison of characteristic parameters of solar cell.

| Types of solar cells | Theoretical efficiency (%) | Maximum efficiency (%) | Mass power ratio (W/kg) | Flexibility |
|----------------------|-----------------------------|------------------------|-------------------------|-------------|
| Si                   | 29                          | 24.85                  | 455                     | inflexible  |
| a-Si                 | 28                          | 7                      | 557                     | flexible    |
| SHJ                  | 26                          | 20.5                   | 1190                    | flexible    |
| GaAs                 | 38                          | 31                     | 2467                    | flexible    |
| CIGS                 | 28                          | 19.9                   | 1500                    | flexible    |

The flexible CIGS thin film solar cell is the best choice for small solar UAV because of its low price, good low light performance, high specific energy, better adaptability to the airfoil surface of UAV and improved wing area coverage. In order to realize the efficient collection and utilization of solar energy by small CIGS solar UAV, a set of reliable and efficient energy management system is essential. The working principle and efficiency of each part are shown in figure 1.

Figure 1. Working principle and efficiency of energy power system of solar UAV[2].

It can be seen that the energy collected by solar cells will be continuously consumed in the process of energy management system[3], and the actual energy utilization rate can only reach about 10%[4]. Therefore, only by improving the conversion efficiency of each part of UAV energy management and optimizing the flight path through intelligent flight control system, can small CIGS solar UAV become mature.

2.2. Power system

For propulsion system, in order to improve the reliability of the system, the large solar UAV usually adopts the distributed propulsion system with extended wingspan[5], and it is usually based on direct drive, which is no longer applicable for the small CIGS solar UAV. In order to ensure its long endurance, it is necessary to reduce the power consumption of the UAV and provide enough traction. Therefore, it is necessary to design an efficient gearbox, that is, to drive the efficient propeller by the way of deceleration of the brush less motor. By using the gearbox, the force efficiency of the motor can be improved. The structure of gearbox is shown in figure 2.
3. Key points in overall design

3.1. Aerodynamic layout design
Aerodynamic layout is an important factor affecting flight performance. Different layout have different wing positions[6]. Due to different design tasks and performance requirements, there are many types of aerodynamic layout. At present, there are many kinds of aerodynamic layouts that can be applied to solar UAVs, as shown in figure 3, which have their own characteristics.

Conventional layout and T-tail layout are simple and easy to realize, with mature supporting technology and profound theoretical accumulation. The UAV's control performance and flight performance are relatively balanced. But the flat tail usually produces negative lift to balance the pitching moment, which affects the aerodynamic efficiency of the whole aircraft; the wing layout is simple, the fuselage and the wing are integrated, and the streamlined fuselage can also provide part of the lift, with small air resistance and high aerodynamic efficiency of the whole aircraft. However, due to less control surface, insufficient stability, low maneuverability and wind resistance, it is not suitable for cruising in low altitude complex environment; the double vertical tail layout is compact, with large...
wing area, good maneuverability, and the independent cabin design is convenient to better adjust the center of gravity. The power layout is flexible, which can adopt the front pull type and the rear push type, and solar cells can be laid on the main wing and horizontal tail. In addition, it is easy to realize miniaturization and modularization through detachable design, which is convenient for transportation and delivery in practical application.

3.2. Airfoil design
Airfoil is the main source of lift for fixed wing UAV. Airfoil selection and weight reduction structure design have an important impact on aerodynamic characteristics. In order to maximize the efficiency of the whole aircraft, the appropriate airfoil should be selected according to different flight requirements. Due to the low wing load of solar UAV, in the selection of airfoil, in addition to considering the lift drag ratio, it should also reduce the drag and facilitate the laying of CIGS solar cells. Figure 4 shows the commonly used airfoil parameter curves of several solar UAVs.

![Comparison of three airfoil parameters](image)

Figure 4. Comparison of three airfoil parameters: (a) lift coefficient; (b) drag coefficient; (c) lift drag ratio coefficient; (d) moment coefficient.

It can be seen that at a specific Reynolds number, SD7037 airfoil has higher angle of attack at maximum lift drag ratio, reaching 7 degrees, which is closer to the stall angle of attack. When the angle of attack is greater than 7 degrees, the drag coefficient rises sharply, resulting in a very sharp change in the lift drag ratio for the angle of attack, which shows that if the UAV has a slight attitude change in the air, it will easily lead to wavy flight or even stall. Although the drag coefficient of MH114 airfoil is slightly larger than the other two airfoils, the lift coefficient and lift drag ratio are the
highest, and the change of lift drag ratio curve is relatively gentle. The large thickness of the trailing edge of the airfoil facilitates the installation of avionics equipment and the manufacture of aileron surface, so MH114 is the best choice among these airfoils.

3.3. Flight platform design

From the working mode of the small CIGS solar UAV, it can be concluded that in cruising, only with a small power consumption and a minimum sink rate glide, can the endurance of small CIGS solar UAV be maximized. The relationship of sink rate is as follows:

\[ V = v \sin \alpha = v \frac{C_D}{C_L} = \sqrt{\frac{2}{\rho}} \times \sqrt{\frac{W}{S}} \times \frac{C_D}{C_L^{3/2}} \]  

(1)

Where, \( V \) is the sink rate; \( v \) is the speed of aircraft; \( \alpha \) is the glide Angle; \( C_L \) is lift coefficient; \( C_D \) is the resistance coefficient; \( \rho \) is the density of the atmosphere; \( W \) is the aircraft gravity; \( S \) is the reference area of the wing.

By equation (1), the optimum sinking rate point of design is in \( \min (v \sin \alpha) \) [8]. There are two main factors influencing the sink rate: The wing load \( \frac{W}{S} \) decreases not much due to the square root of the wing load, so the aircraft's sinking rate mainly depends on the power factor \( \frac{C_L^{3/2}}{C_D} \). The power required for flat flight is:

\[ P = T \times v = \frac{\rho v^3 S C_D}{2} = \sqrt{\frac{2}{\rho}} \times \sqrt{\frac{m^3}{S}} \times \frac{C_D}{C_L^{3/2}} \]  

(2)

Where: \( T \) is the thrust; \( M \) is the mass of the aircraft.

According to equation (2), in addition to being proportional to \( v^3 \), flat flight power is also related to airfoil load \( \frac{m}{S} \) and power factor \( \frac{C_L^{3/2}}{C_D} \). Therefore, the speed should be reduced as far as possible, and according to the airfoil, select the appropriate angle of attack to improve the flight performance of the aircraft[9]. An aircraft has the following relationship when cruising:

\[ L = W \]  

(3)

\[ D = T = \frac{\rho v^3 S C_D}{2} \]  

(4)

Where: \( D \) is resistance.

Under the condition of subsonic velocity, the total drag coefficient of aircraft is[10].

\[ C_D = C_{D0} + \frac{C_{eL}^2}{\pi e \lambda} \]  

(5)

Where, \( C_{D0} \) is zero lift resistance coefficient; \( e \) is the Oswald efficiency factor; \( \lambda \) is the aspect ratio of the wing.

Among them, flight resistance is mainly divided into vortex induced resistance and airfoil resistance, when the flight speed is low, the total drag mainly depends on the vortex induced drag. Increasing the aspect ratio can reduce the vortex drag and improve the aerodynamic efficiency of the wing. However, the wing structure with large aspect ratio will inevitably bear large stress at the wing root. When overload occurs, the wing deformation will exceed the limit[11], which will affect the reliability of UAV. In addition, in order to make the small CIGS solar UAV obtain enough energy, part of the aerodynamic efficiency (aspect ratio of 6-10) can be sacrificed in the miniaturization design, so as to obtain the appropriate laying area and install solar cell components. In order to improve the anti wind ability of UAV and the structural instability caused by overload in flight, a large number of new materials or composite materials must be used in the main structure of solar UAV, such as light wood, carbon fiber composite materials, Kevlar, etc., so as to reduce the weight of UAV itself and increase the payload.
4. Conclusion
This paper mainly analyzes the basic characteristics of the energy and power system of small CIGS solar UAV, and systematically studies some key issues in the overall design, and draws the following conclusions:

1) Flexible CIGS solar cell has excellent deformation resistance and high specific energy, which is suitable for integrated structure design. The actual energy utilization rate of photovoltaic system can only reach 10%. The coupling matching of energy and power system is the key to the research and development of small solar UAV.

2) The aspect ratio of small-scale CIGS solar UAV can be 6-10, and the effective solar cell laying area should be considered at the same time. The double vertical tail dynamic layout can be used as a layout choice of small CIGS solar UAV.

3) In order to reduce the power consumption of the aircraft, it is necessary to make it glide with the minimum sinking rate in airfoil selection and overall design, improve the lift drag ratio and power factor of the airfoil, and reduce the wing load, so as to reduce the sinking rate of the aircraft.

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