Lightweight Research on Wireless Charging System for Unmanned Aerial Vehicles Based on High Efficiency

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Abstract: Unmanned aerial vehicles (UAVs) are characterized by safety, flexibility, and economy, and are widely used in many fields. At present, due to the limitation of UAV loads and the bottleneck of battery technology, UAVs can't carry out missions for a long time. The wireless charging system for UAVs has the advantages of safety, flexibility, automation, and environmental adaptability, so it has gained wide attention. Electromagnetic induction wireless energy transmission system is a system that transmits electrical energy through a magnetic field, and in electromagnetic induction wireless energy transmission system, it is necessary to reach the goals of lightweight, high efficiency, anti-skewing, and modularization. In order to achieve the goals of high efficiency and anti-deviation, this paper adopts three sets of series-connected rounded rectangular coils as the transmitting stage to improve the charging efficiency and anti-deviation ability; in order to achieve the goal of lightweight, this paper reduces the weight by changing the material of the magnetic core, and using the annulus core amorphous alloy core; in order to achieve the goal of modularity, this paper designs to carry multiple sets of receiving coils, which can be switched on and off according to the demand in order to satisfy the different power requirements. Finally, a bilateral LCC compensation topology network is established to control the input and output currents to achieve the design goal. The method proposed in this paper helps to realize the automatic charging of UAV and improve the endurance of UAV, so as to enhance the working hours and inspection range of UAV, and make UAV capable of doing more work.

Keywords: drone, wireless charging, magnetic coupling mechanism.

1. Introduction

UAVs are widely used in geology, meteorology, agriculture, military, etc., because they have the ability to accomplish all kinds of complex tasks efficiently, flexibly and safely. The endurance of a UAV determines the time and range of the UAV's mission. However, due to the bottleneck of battery technology, the current endurance of multi-rotor UAVs is usually only 20-40 minutes, which makes it impossible to carry out long-time and wide-range operations. Increasing the battery capacity will also increase the weight of the UAV and make the UAV less flexible. Therefore, new requirements for UAV electrical energy replenishment technology have arisen. The traditional methods of power replenishment include: installing solar panels on the UAV to realize energy self-sufficiency in flight [1], but it is more suitable for large UAVs; building charging base stations and using manipulators to

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replace batteries for UAVs [2], but it requires special modification of UAVs and higher precision requirements; The third method is to build a contact electrode charging platform [3], but it has problems such as exposed electrodes are easy to aging, short-circuit and other dangers in wet weather, and contact charging requires high positioning accuracy for UAVs. Therefore, there is a need to develop a new type of UAV charging system that has strong safety, is not easily disturbed by the environment, and is less burdensome to the UAV. Wireless charging technology has been widely utilized in many electrical fields, and compared with other charging methods, wireless charging technology has the advantages of safety, flexibility, automation, etc., and also has unique advantages in harsh environments and unattended occasions [4]. Therefore, wireless charging technology can be used in the field of UAV charging, so that the UAV can be charged in the hovering state, which not only has high safety and stability, but also reduces the number of landings and takeoffs of the UAV, and reduces the risks that may occur in the process, which is of practical significance.

Wireless energy transmission was proposed by Tesla in 1891, and it can be generally categorized into microwave type, laser type, induction type and electric field type. In this paper, we mainly use the electromagnetic induction type wireless energy transmission system (IPT), which transmits electrical energy through magnetic fields. There are several main issues that need to be solved by using this system: the first is the effect of the coupling structure on the performance of the UAV. The coupling mechanism increases the load on the UAV and the external coupling mechanism creates additional wind resistance and may interfere with the loading of the UAV equipment. The second issue is the efficiency of charging, which should be maximized without affecting the UAV flight efficiency. The last one is the anti-deviation ability. When hovering charging, the wind and other influences can easily shift the position of the UAV, leading to a reduction in charging efficiency or even unable to charge. Therefore, it is necessary to improve the offset resistance of wireless charging in the design of magnetic coupling structure. Many research teams at home and abroad have studied these two aspects and have achieved a series of results. In terms of the coupling structure, Imperial College of Science and Technology (UK) replaces the UAV collision avoidance frame with the wireless charging system receiving coil to reduce the weight of the UAV [5], but the receiving coil is at the same height with the UAV, and the magnetic flux will pass through the fuselage of the UAV during wireless charging, which will cause electromagnetic interference to the UAV; Team from Tsinghua University and others have placed the receiving end of the wireless charging system of the UAV under the belly of the aircraft [6-8], which can shorten the distance between the receiving coil and the transmitting coil to improve the coupling coefficient, but it will increase the received wind resistance, which affects the performance of the UAV, and it will also affect the normal use of on-board external equipment; the Korea Advanced Institute of Science and Technology proposed a vertical solenoidal method of the receiving coil of the wireless charging system for UAVs, which is mounted on the landing gear of the UAV [9-10], which can effectively reduce the electromagnetic interference to the UAV,but requires modification of the UAV structure and is easily damaged. In terms of offset resistance, L'Aquila University (Italy) and Imperial College (UK) proposed methods to improve the offset resistance by increasing the coverage area of the transmitting coils [11-12], which can effectively improve the offset resistance but reduces the efficiency; Wuhan University team proposed an arrayed transmitting coil platform [13], which consists of four transmitting coils corresponding to one receiving coil turning on the corresponding coils by accepting signals. coils by receiving signals. However, this method needs to be equipped with a position detection device, which is costly and less stable.

In this paper, by combining the current achievements in wireless charging for UAVs, a wireless charging configuration scheme for UAVs is proposed to achieve the effect of balancing the flight performance of UAVs, the charging efficiency, and the anti-offset capability during charging.

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2. Design of magnetic coupling mechanism

2.1. Design requirements

The design of the magnetic coupling mechanism is an important factor in UAV wireless charging technology, which will not only relate to the wireless charging efficiency of the UAV, but may also have an impact on the flight efficiency of the UAV. The design of the magnetic coupling mechanism needs to meet the following points:

1, high energy transfer efficiency;
2, strong anti-interference ability;
3, lighter quality;
4, not easy to be damaged;
5, the use of coplanar design to reduce the additional wind resistance to the UAV.

2.2. Installation position of the receiving end of wireless charging system

The current mainstream magnetic coupling mechanism is generally categorized into three major types, which are installed on the belly of the UAV, the fuselage of the UAV, and the landing gear of the UAV. When the magnetic coupling mechanism is installed on the fuselage of the UAV, the magnetic flux passed during wireless charging may circulate through the fuselage and cause interference to the UAV, and the distance from the transmitting end is far away, which is less efficient. Installing the magnetic coupling mechanism at the bottom of the UAV is likely to affect the use of other on-board equipment. In this paper, we adopt the practice of installing multiple receiver coils on the landing gear of the UAV, as shown in Figure 1. This practice can further reduce the distance between the transmitting end and the receiving end, improve the system coupling coefficient and then improve the charging efficiency, and does not easily affect the normal use of airborne equipment.

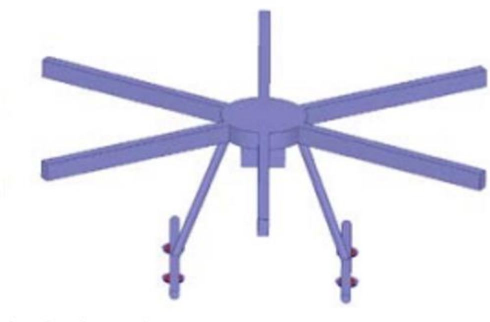

Figure 1: position of the receiving end

2.3. Coil shape selection

Simulation of the self-inductance and mutual-inductance effects of different shapes of coils, the result is that in the case of the same amount of wire, the self-inductance mutual-inductance coefficient of the square coil is the best, and the circular coil has the characteristics of the most uniform distribution of the magnetic field, and the combination of the two, the rounded rectangle coil test, found that the rounded rectangular coil in the distribution of the magnetic field, the coupling coefficient and self-inductance mutual-inductance coefficient have a more obvious advantage. Therefore, the coil shape is selected rounded rectangular coil.In addition, it is stated in the literature[14] that the use of symmetric stacked layer structure in the transmitting coil and receiving coil can also enhance the anti-deviation ability.

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2.4. Transmitter coil structure

The use of multiple sets of transmitting coils is conducive to improving the efficiency and anti-deviation ability of the UAV wireless charging system. When neighboring coils pass current in opposite directions, the magnetic fields generated by the current will weaken each other, reducing the charging efficiency. Therefore, multiple groups of coils should use the same direction of current. The number of coils in series at the transmitter side is analyzed, and the simulation of 1, 2, 3 and 4 groups of coils in series is carried out, and it is found that the magnetic field generated by three groups of coils is the most uniformly distributed and has the strongest anti-deviation ability. Therefore, the UAV wireless charging system adopts three sets of series-connected rounded rectangular coils.

2.5. Receiver-side magnetic core design

Comparing the non-magnetic core, cross-shaped core, annulus core, and full-coverage core, it is found that the self-inductance and mutual inductance coefficients at the receiving end of the added annulus core and full-coverage core are significantly larger than those of the other two groups, while the internal resistance is significantly smaller than that of the other two groups. , while the internal resistance is significantly smaller than that of the other two groups. In addition, the difference of the above parameters between the annulus iron core and the full-coverage iron core is small, and for the consideration of the principle of lightweighting, the annulus magnetic core is selected.

2.6. Selection of magnetic core material for magnetic coupling mechanism

The ideal magnetic core material for wireless charging system design should have the characteristics of high saturation magnetic flux density, high permeability, high resistivity, low power loss, strong thermal stability and low cost.

Currently, manganese-zinc ferrite is mostly used as the magnetic core of wireless charging system. However, the brittleness of manganese-zinc ferrite leads to the system made of it is easy to produce mechanical fracture, can not be processed into complex parts, in addition to its magnetic flux density saturation low point, meaning that the system needs to consume more materials, and lightweight requirements contradictory; magnetic permeability is low, the coupling coefficient is low, the leakage of magnetism is more serious, and it is easy to interfere with the unmanned aerial vehicle. Comparison of commonly used magnetic core materials on the market, found that amorphous alloy has the following advantages:

1, amorphous alloy materials are stronger and can be processed into more complex shapes.

2, Higher magnetic permeability, which can reduce the effect of magnetic flux on the UAV body.

3, Higher saturation magnetic flux density, less material required to achieve the same effect.

4, Saturation magnetic flux density is less affected by temperature, which can be adapted to more working environments.

After simulation, in other conditions are the same, in order to achieve the same power, the amorphous alloy quality relative to ferrite is smaller, in line with the lightweight requirements.

2.7. Summary

This paper summarizes the design of the magnetic coupling mechanism for wireless charging of UAV around the factors of quality and charging efficiency, and proposes that the transmitting end adopts series connection of three groups of rounded rectangular coils, and the receiving end uses multiple groups of annulus amorphous alloy material cores, which are mounted under the landing gear of the UAV, in order to achieve the purpose of lightweight, high efficiency, and resistance to deflection.

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3. Circuit Design

3.1. Modularization of the system

In order to meet the power requirements of UAV charging in different situations, the circuit of the system should be modularized so that it can change the charging power.

In order to realize the modularity of the receiving end of the wireless charging system of the UAV, the UAV can be made to carry multiple sets of the same receiving modules, and the modules can be switched on and off as needed when charging, and the current generated by multiple modules can be rectified and then output in parallel. Considering the lightweight requirement and the UAV balance problem, it is chosen to load four groups of receiver modules for the UAV landing gear.

The KVL equation is calculated for the circuits with different numbers of modules turned on, according to the calculation, the more modules are turned on, the higher the charging efficiency is, and the different power requirements of UAV charging have been met by changing the number of modules turned on.

3.2. UAV wireless charging system circuit design

The input voltage at the transmitting end first forms an AC voltage through the inverter, and then passes the power to the receiving end through the bilateral LCC compensation topology circuit, forms a DC output through the rectifier, and finally generates a constant current output through the power converter to charge the lithium battery carried by the UAV.

3.3. Inverter design for UAV wireless charging system

The role of the primary side inverter is to realize voltage conversion. The input voltage is first input filtered, after which the AC voltage is generated by full-bridge inverter circuit, and finally filtered through the output. Although the number of switching tubes used in the full-bridge inverter circuit is doubled compared to the half-bridge inverter circuit, and the cost and quality are higher, the amplitude of the output voltage on the AC side of the inverter circuit is twice as high as that of the half-bridge inverter circuit when the DC source voltage is the same, the charging efficiency is higher. During the period, the input voltage and current, output voltage, current, temperature and other parameters are sampled, and protection circuits are set up for over-voltage, over-current, over-temperature and other abnormalities, so as to eliminate potential safety hazards.

3.4. UAV wireless charging system power converter design

When charging, the receiving end of the UAV wireless charging system should have constant current output capability. The P-P topology can be used to realize the constant current output. Meanwhile, the DC-DC method is used as the control scheme, and the buck converter is selected to realize the constant current and constant voltage output. Pulse width modulation (PWM) is one of the main control methods of Buck converter, which has the advantages of small control voltage ripple, fixed switching frequency and easy filter design. Average current mode control compares the current flowing through the inductor with the error signal of the output voltage, amplifies the difference and then compares it with the sawtooth wave to generate PWM signals to realize the PWM control of the switching tubes, which is able to achieve the goal of constant current and constant voltage control, and has a simple structure and small module size, which meets the requirements of lightweighting; and multi-modules work in parallel to meet the requirements of modularization. Therefore, the average current control method is used to design the compensation design for the current inner loop and voltage outer loop to achieve the design goal.

3.5. Summary

In this chapter, the circuit of the wireless charging system for UAVs, the inverter and power converter in it are designed to reach the modularity goal, constant voltage input and constant current output.

4. Conclusion

UAV wireless charging technology can effectively improve the UAV cruising ability, which is of great significance in today's increasingly widespread use of UAVs. This paper takes the UAV wireless charging system as the main object for research, for the UAV wireless charging lightweight, high efficiency, anti-offset requirements in the magnetic coupling mechanism, circuitry to integrate a UAV wireless charging system that can have lightweight, high efficiency, anti-offset at the same time. The results obtained in this paper are as follows:

1, the existing research related to UAV wireless charging system is explained.

2, The design of the magnetic coupling structure was carried out: the transmitting end adopts the method of connecting three sets of rounded rectangular coils in series, and the receiving end uses a back-type amorphous alloy material core, which is mounted under the landing gear of the UAV, in order to improve the charging efficiency, reduce the weight of the magnetic coupling mechanism, and improve the anti-offset capability.

3, the design of the circuit structure is carried out, and the inverter and power converter are designed so that the receiving end can output constant-current or constant-voltage DC power, and the charging power can be changed according to the needs.

The method proposed in this paper can effectively improve the efficiency and anti-interference ability of hovering wireless charging for UAVs, and it has less impact on UAVs, meets the design requirements of lightweight, high efficiency, and anti-deviation, and is conducive to improving the endurance of UAVs, so as to increase the working time and range of the UAVs, and make the UAVs capable of doing more work.

However, the hovering UAV wireless charging system summarized in this paper still has some defects.

The receiving end is installed on the landing gear, which is easy to be damaged and easy to generate additional wind resistance.

2. The amorphous alloy material used in the receiving end core is more conductive than the ferrite material, which is easy to generate eddy currents, and cannot be applied to the overpowering scenario.

3. Multiple receiving ports are used in this paper to realize the modularity, but carrying multiple modules at the same time does not meet the requirement of lightweighting.

4. The problem of heat dissipation during charging is not considered.

The above problems need to be solved by subsequent research.

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