Wireless Charging System Using Soft Magnetic Composite for Unmanned Aerial Vehicle

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Abstract: Demand and interest in unmanned aerial vehicle (UAV) technologies has been rapidly growing. Most of UAVs use the battery for their operation, despite of its heavy weight and long charging time. The wireless charging system for drones is on increasing demand, to avoid the shortcomings of battery. Typical wireless charging system utilizes the ferrite for improving power transfer efficiency, but the brittleness of ferrite characteristics deters its application to dynamic UAV operation. In this paper we proposed a wireless charging system using the developed soft magnetic composite. For validation, the proposed wireless charging system was implemented with typical wireless charging system. And power transfer efficiency and intensity were measured and compared with conventional ones.

• *Key-Words:* wireless charging, unmanned aerial vehicles (UAV), soft magnetic composite (SMC)

1 Introduction

Recently, the unmanned aerial vehicle (UAV) technology which were mostly applied to military applications, begun to expand its application areas to the public or private sectors due to its technological advancement [1]. Drones have the potential unlimited due to the operational advantages in reliability, maneuverability and cost effectiveness [2],[3],[4]. The applications of photography or videography demonstrated the feasibility of fast growth, and emerging applications have been expected in areas of traffic monitoring, delivery services, forest fire surveillance, and monitoring hazard area or ecosystems [3],[5],[6]. One of challenging issues remains to be addressed, for most of drones rely on the battery with limitations on capacity and weight [8]. The wireless power transfer(WPT) would be an alternative technology to deal with the issue of electric energy needed for UAV [7],[8],[9],[10]. It can enable drones to increase their flying range, operation time and will promote the autonomous flying. An inductive WPT has been adopted successfully various electric-powered vehicles for years, including our earlier development of wireless powered electric bus. The inductive WPT system generally consists of a transmitting coil (Tx coil) and a receiving coil (Rx coil), while Tx coil of our electric bus was implemented as segmented loops under the surface of road throughout the bus route.

The principle of inductive WPT is based on Faraday's law, with the time-varying magnetic field generated by ac Alternating Current (AC) in Tx coil. The time-varying magnetic field from Tx coil is coupled to Rx coil through the air, yielding the time-varying current in Rx coil by the coupled magnetic field. The output voltage is then developed across the Rx coil terminals, where the designated DC voltage can be converted from AC voltage at Rx coil. The principle of inductive WPT is clear and was applied successfully to our Electric Bus as the main power source using customized Tx-Rx structure. An inductive WPT can be applied to UAV based on the same principle of Faraday's Law. The practical implementation of an inductive WPT system uses the ferrite as one of the types of ferromagnetic materials in order to improve magnetic coupling. Ferrite is known to have characteristics of excellent high-frequency characteristics in magnetic permeability and suitable electrical properties like electrical conductivity.

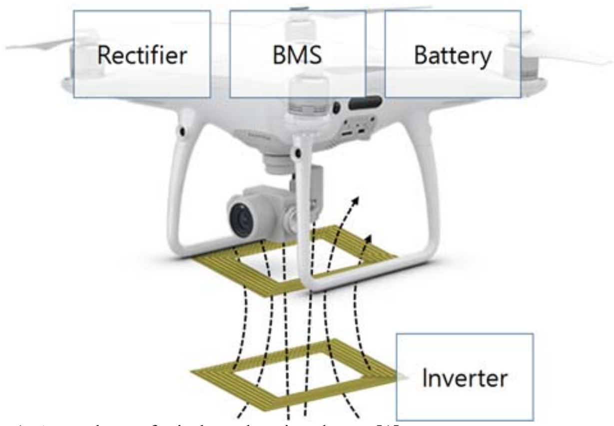

Fig. 1. A topology of wireless charging drone. [1]

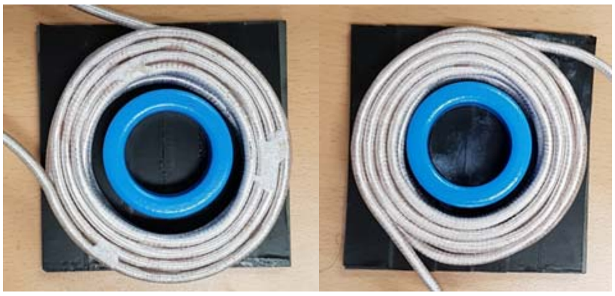

Fig. 2. Transmitting(left) and receiving(right) coils. The Litz wire used in coil fabrication is 0.12 mm thick and has 300 strands. Both coils have a diameter of 9.7 cm and have a turn number of 16 turns. The transmission side magnetic body used the conventional magnetic ferrite, while the receiving side magnetic body alternately tested the conventional ferrite and the proposed SMC.

Fig. 3. The developed SMC (left) and conventional ferrite (right)

Although a ferrite is an optimized device for guiding magnetic field with desired efficiency in general, it might be less practical using a ferrite for WPT of drones. The ferrite's characteristics of brittleness deters the WPT application in under extreme dynamic environment of drone's operation. There were several works to enhance the performance of UAV, but unable to take it into account for the efficient ferrite magnetic material with WPT because of limited practical perspectives. The soft magnetic composite in this paper would be an alternative to ferrite as a magnetic material in its electrical and mechanical properties, for the purpose of integrating an inductive WPT system to drones.

In this paper, different ferromagnetic materials were studied for applying magnetic core in drone's WPT system. This comparative study was conducted based on newly developed soft magnetic composite (SMC) and conventional ferrite used as the magnetic core of WPT system. In particular, the selection of suitable ferromagnetic core materials for drone's WPT system is mainly discussed by considering harsh environments.

2 Topology of Drone Wireless Charging Coil

A typical WPT system for drone application consists of an inverter, two loop coils, resonant matching capacitor, a rectifier, BMS and a battery, as shown in Fig. 1. The battery can be charged using a magnetic field from the source coil. The source and load coil are designed for charging DJI phantom.

Fig. 4. Free fall comparison experiment at 1m height

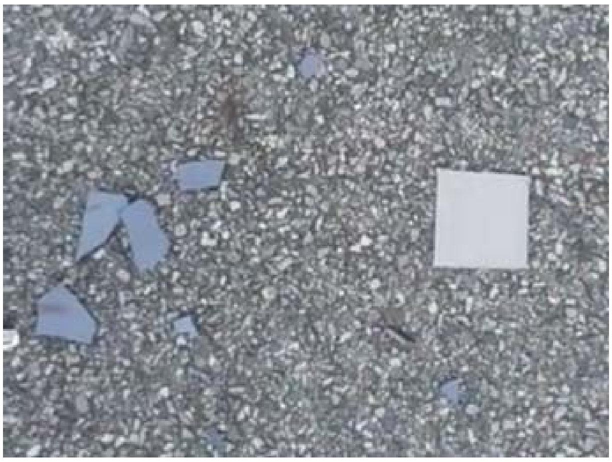

Fig. 5. Drop test results of two magnetic bodies

As shown in Fig. 2, the magnetic materials plate and round magnetic core were used for increasing power transfer efficiency and decreasing electromagnetic interference due to the magnetic field from the Tx coil. The capacitors were added to compensate the leakage inductance of coil and adjust the resonance frequency of coil system. Moreover, the matching capacitance enhanced the magnetic flux density of WPT system.

The WPT coils were fabricated using ferrite and developed SMC. The permeability of ferrite is 3200 (μ_r=3200) and the permeability of developed SMC is 200 (μ_r=200). Unlikely the transformer, the WPT system has large air gap between Tx and Rx coil. Therefore, the major factor of determine the effective permeability is permeability of air which has 1 (μ_r=1). As the air gap is increased, the effective permeability is accordingly decreased. In drone applications, the permeability of magnetic material is not major factor to determine the power transfer efficiency due to the large air gap.

3 Experiment and Discussion

3.1 Free fall test of magnetic materials

A free fall test was conducted to compare the strength of the newly developed SMC with that of the conventional ferrite. Fig. 3. shows developed SMC and conventional ferrite. Both magnetic bodies are 5mm in thickness and 100mm * 100mm in size. A free fall test was carried out at a height of 1 m and both magnetic bodies were simultaneously dropped as shown in Fig. 4. The free fall test results are shown in Fig. 5. According to the experimental results, the conventional ferrite was completely destroyed while the developed SMC is still in its original form. A developed free fall test at 3m and 5m high also did not destroy the developed SMC. In additions, in the hammer-down experiment, the developed SMC was not destroyed, but it was only crumpled. It is very likely that a drone's drop in the height of a few meters during the maneuvering.

The prototype of drone's WPT system should be preserved as much as possible, though the conventional ferrite failed to satisfy this requirement and would be likely broken. The newly developed SMC was never damaged even when dropped from several meters in height, thus the new SMC is acceptable for application to drone's inductive wireless charging systems.

3.2 Comparison of the change of the mutual inductance according to the air gap

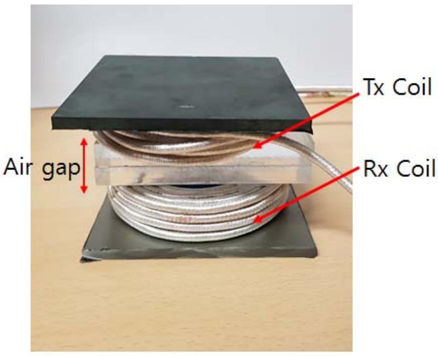

Fig. 6. Measurement of mutual inductance change

It is important to note that the mutual inductance can effect on the efficiency of inductive WPT system. Especially, the induced voltage in Rx coil is proportional to mutual inductance and output power performance is dependent on the induced voltage. For this reasons, the change of mutual inductance was measured considering different magnetic materials as shown in Fig. 6. The conventional ferrite and new SMC were alternately applied to the magnetic material of the Rx coil and the mutual inductance value according to the gap was measured. Fig. 7 shows the change in the mutual inductance. According to measurement results, there was almost no difference in mutual inductance between two magnetic materials depending on the varying distance.

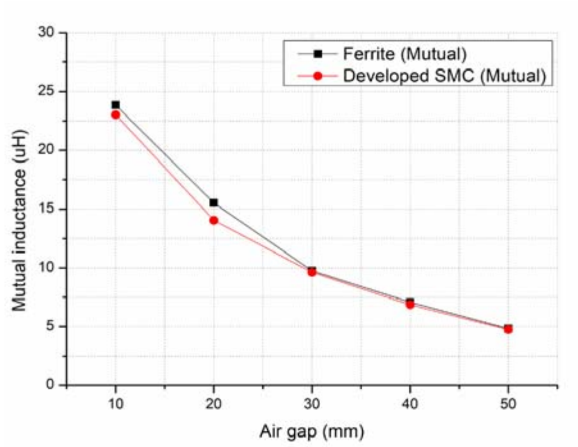

Fig. 7. Comparison of mutual inductance change according to air gap

3.3 Comparison of magnetic characteristics by wireless power transfer experiment

Tx and Rx coils were fabricated for wireless power transfer experiments. Tx and Rx coils are shown in Fig. 2. The inductance values of coils fabricated for WPT system were measured. The operating frequency of system was set at 19kHz and the capacitor value of compensation circuit was calculated as close as possible. The gap between two coils was 2.5 cm. The measured parameters are shown in Table 1.

Experiments were conducted under the same condition that a sinusoidal current of 19 kHz was applied through a current inverter to receive 50 watts of power on the load side. The load was directly connected to AC output without a rectifier or regulator, and the load used was a 5 Ohms resistor. The waveform of the input voltage and current applied to the wireless power transfer system is shown in Fig. 8. The input of WPT system is equal to the output of the inverter. The voltage delivered to the load in each case is shown in Fig. 9. When

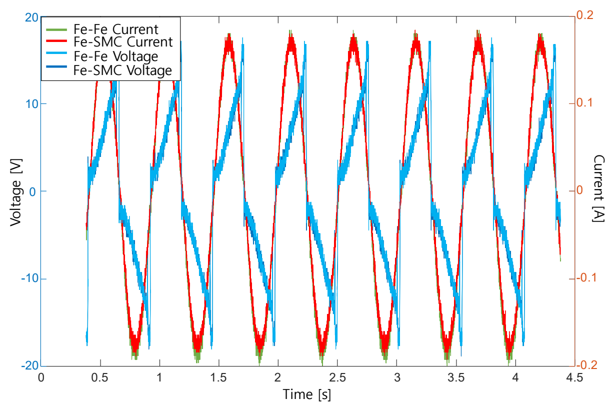

Fig. 8. The output voltage and current of the inverter when 50 watts of power is delivered to the load. In the case of Fe-Fe, the conventional ferrite is used for both the Tx coil and the Rx coil. For the Fe-SMC, the conventional ferrite is used for the Tx coil and the SMC is used for the Rx. The current and voltage of both cases are almost the same.

delivering 50 watts of power to a load, the voltage across the load is almost the same in both cases. Table 2 shows the input power, output power, and efficiency for each case.

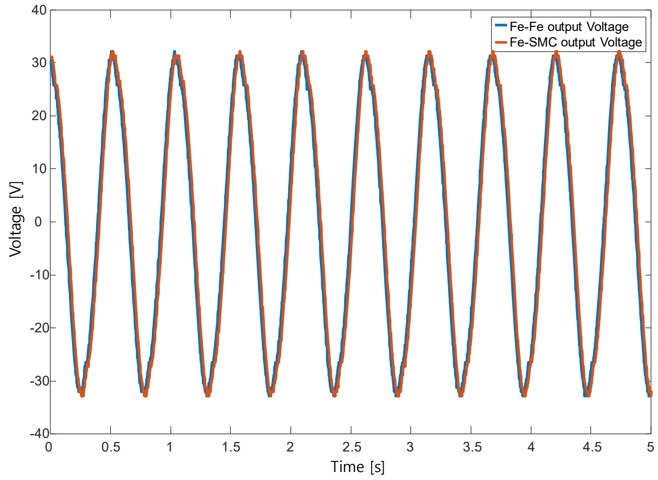

Fig. 9. Voltage waveform delivered to a load

TABLE I. PARAMETER VALUES OF COILS AND COMPENSATION CIRCUITS

parameters	***Rx side magnetic material***	
	Conventional ferrite	***Developed SMC***
Input power	84.47 W	82.82 W
Output power	50.76 W	51.05 W
Efficiency	60.08 %	61.64 %

TABLE II. PARAMETER VALUES OF COILS AND COMPENSATION CIRCUITS

parameters	***Rx side magnetic material***	
	Conventional ferrite	***Developed SMC***
System operating frequency	19kHz	19kHz
Tx coil inductance	44.9 μH	44.9 μH
Tx compensation capacitor	1.533 μF	1.533 μF
Tx resonance frequency	19.18 kHz	19.18 kHz
Rx coil inductance	42.84 μH	41.5 μH
Rx compensation capacitor	1.61 μF	1.61 μF
Rx resonance frequency	19.16 kHz	19.47 kHz
Mutual inductance	14.27 μH	13.58 μH
Coupling coefficient	0.325	0.315

The results show that the developed SMC and conventional ferrite have little difference in WPT characteristics. The same Rx coil voltage was induced at almost the same transmission current. At the same time, the same power was transferred and the efficiency of the system was almost similar.

4 Conclusion

In this paper, the performance of developed SMC for UAV's WPT system in the magnetic core part is identified. From the free fall test, it is found that developed SMC has outstanding mechanical characteristic compared to conventional ferrite. It should be noted that the magnetic core material included drone's components requires good robust mechanical properties. With WPT system for drones, we successfully evaluated developed SMC as magnetic c core compared to the conventional magnetic material. It was demonstrated that the power efficiency of WPT system based on developed SMC was 1.02% greater than conventional ferrite. Based on this experimental results, it can be confirmed that developed SMC is suitable magnetic material for magnetic core in drone's wireless charging system.

Acknowledgement

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