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Compact chemical hydride fuel cell system for portable power generation devices

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ABSTRACT

Compact fuel cell power system was developed for portable applications. The power system featuring a PEM fuel cell combined with a chemical hydride hydrogen generator was proposed. The hydrogen generator uses a catalytic hydrolysis reaction to extract hydrogen from a sodium borohydride solution. The fuel cell stack, hydrogen generator, and power management system were evaluated at the various load conditions. An unmanned aircraft was designed and fabricated to validate the possibility of the proposed fuel cell system. The possibility for the utilization of a fuel cell in a small aircraft was validated through the fuel cell powered flight test. The fuel cell system will open new mission capabilities that are not previously possible because providing three times higher flight endurance compared to the existing batteries.

1. INTRODUCTION

Many researchers regard fuel cells as an ideal power source alternative to existing batteries. Assuming a compressed hydrogen tank has only a 6% hydrogen storage weight fraction for hydrogen fuel cells, the energy density would be greater than 1,000 W-hr/kg. In addition, the fuel cell has many advantages in military applications. The fuel cell has a high thermal efficiency because of its electrochemical reaction rather than a combustion reaction, in the conversion path from chemical energy to electric energy. The fuel cell is a silent, reliable and safe device; moreover, it is eco-friendly.

Current portable fuel cell system can be classified by fuel cell types and hydrogen storage methods. Polymer electrolyte membrane fuel cells (PEMFC), which uses hydrogen as the fuel, have been widely used due to its low operating temperature and relatively high power density. Recently, solid oxide fuel cells (SOFC) were applied. An SOFC uses a hydrocarbon fuel at high temperatures, producing a power density higher than that of PEMFC. Compressed hydrogen has been the common hydrogen storage method of choice; however, this method has exhibited problems including high charge pressure and the low storage density. Also, supplying hydrogen to remote locations,

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such as a battlefield, was found to be difficult. AeroVironment, Inc. has integrated a fuel cell system that uses chemical hydride as the source of hydrogen into their unmanned aircrafts. The chemical hydride served as an alternative to compressed hydrogen.

In the present study, compact fuel cell power system was developed for portable applications. Further, the possibility for the utilization of a fuel cell in a small aircraft was validated through the fuel cell powered flight test.

2. Fuel cell system design

The fuel cell system consisted of two main parts: a fuel cell stack and a hydrogen generator, as shown in Fig .1. A 100 W commercial stack was purchased from Horizon Fuel Cell Technologies. The stack was used after performing modifications through which the weight of 41.6% was reduced. The hydrogen generator was manufactured in our laboratory. Hydrogen was generated by a catalytic hydrolysis reaction from a sodium borohydride (NaBH4) aqueous solution. An 8-bit AVR microprocessor was used to control a pump, cooling fans, and valves. The flight speed, ambient pressure, and temperatures of the stack and reactor were recorded in a flash memory of the microprocessor unit during the flight (Kim 2012).

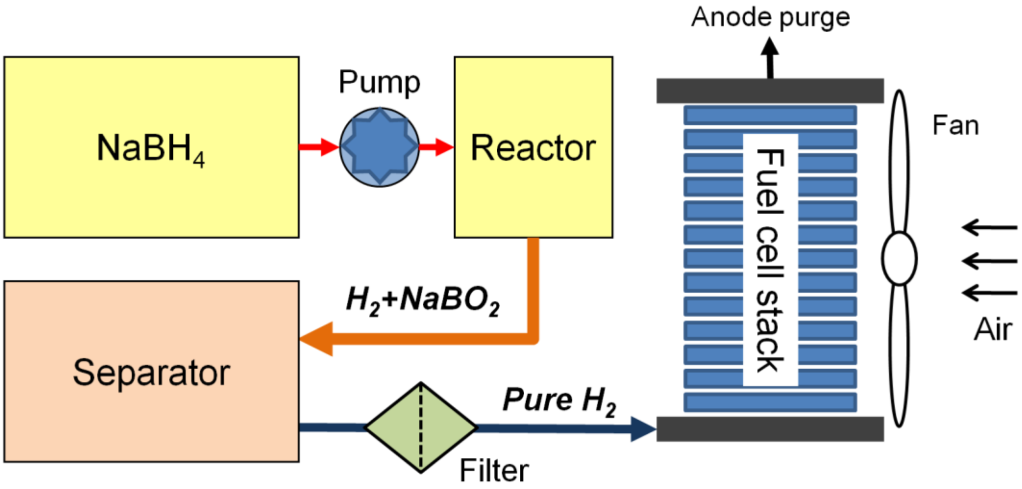

Fig. 1 Schematic of a fuel cell system combined with a NaBH4 hydrogen generator

The fuel cell exhibited a large voltage drop as the electric load increased. Additionally, the fuel cell's power output responded slowly to the sudden electric load. Aircrafts require a large power range and a fast response during takeoff, cruise, maneuver, and landing. Thus, a power management system (PMS) is required that takes the load characteristics into consideration. In the present study, a hybrid fuel cell and battery PMS was designed. The PMS used a lithium-polymer battery (3-cells, 11.1 V, 30 C) that generated a maximum power of 300 W. The battery instantaneously provided power at the sudden increase of a load. While the load was low, the battery recharged using the surplus power of the fuel cell (Kim 2012). Fig. 2 shows a prototype of a compact chemical hydride fuel cell system.

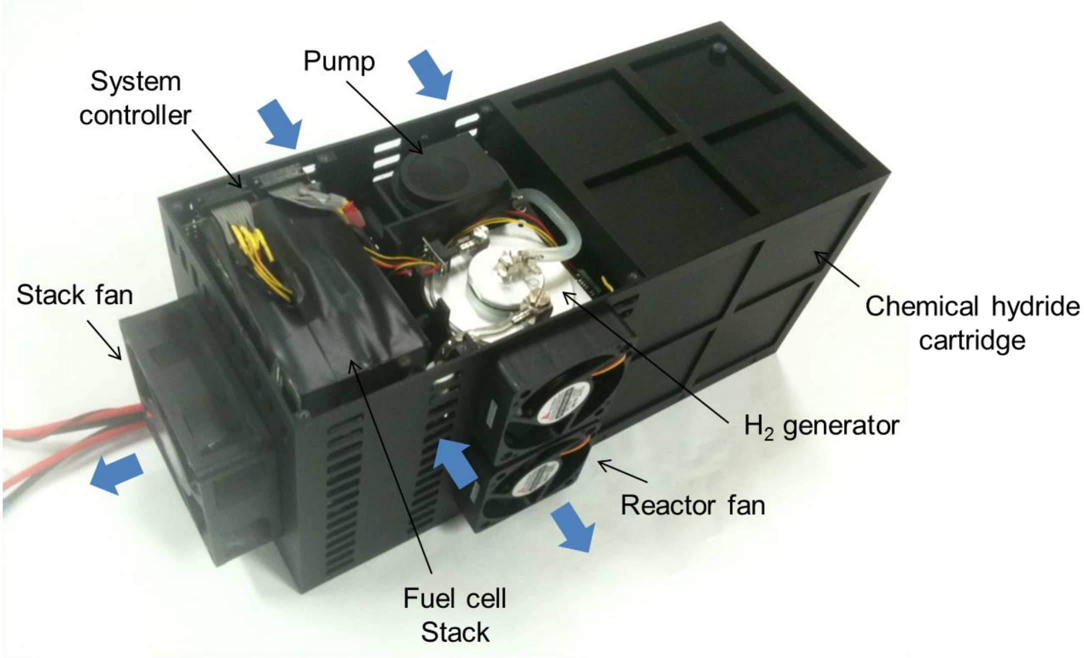

Fig. 2 Prototype of a compact chemical hydride fuel cell system

3. Fuel cell powered aircraft

A demonstration aircraft was designed and manufactured in order to validate the possibility of the fuel cell being used as a power source for an aircraft. The fuselage was designed to provide sufficient volume for integration of the fuel cell system and measuring instruments. A high-aspect-ratio wing was selected to ensure a stable and high endurance flight. The wheels were detached from the fuselage right after takeoff in order to reduce the aircraft weight. The bottom surface of the fuselage was flat to ensure landing without body damages. The fuel cell stack was located in the front of the fuselage in order to directly take the air inflow through the intakes. The NaBH4 cartridge of hydrogen generator was placed on the mass center of the aircraft in order to minimize the change of the mass center due to fuel sloshing and consumption (Kim 2012).

Autonomous fuel cell aircraft flight tests were performed. Considering the energy density of the fuel cell system, endurance higher than 3 hours was possible; however, the flight time target was not achieved due to poor weather and low system reliability. The total flight time was 1 hour 31 minutes as shown in Fig. 3. After the takeoff in which the battery was used, the PMS switched power to the hybrid fuel cell-battery mode. Early in the flight, the power output of the fuel cell increased in order to compensate for the climb flight in which altitude was gained. The fuel cell temperature increased rapidly with the power generation. The temperature changed following the change of power from the fuel cell. The fuel cell generated a stable power output during the entire flight, except for one time 30 minutes after takeoff. This abnormal operation was caused by the sudden change of aircraft attitude due to flight path secession; thus the fuel cell system malfunctioned for a moment (Kim 2012).

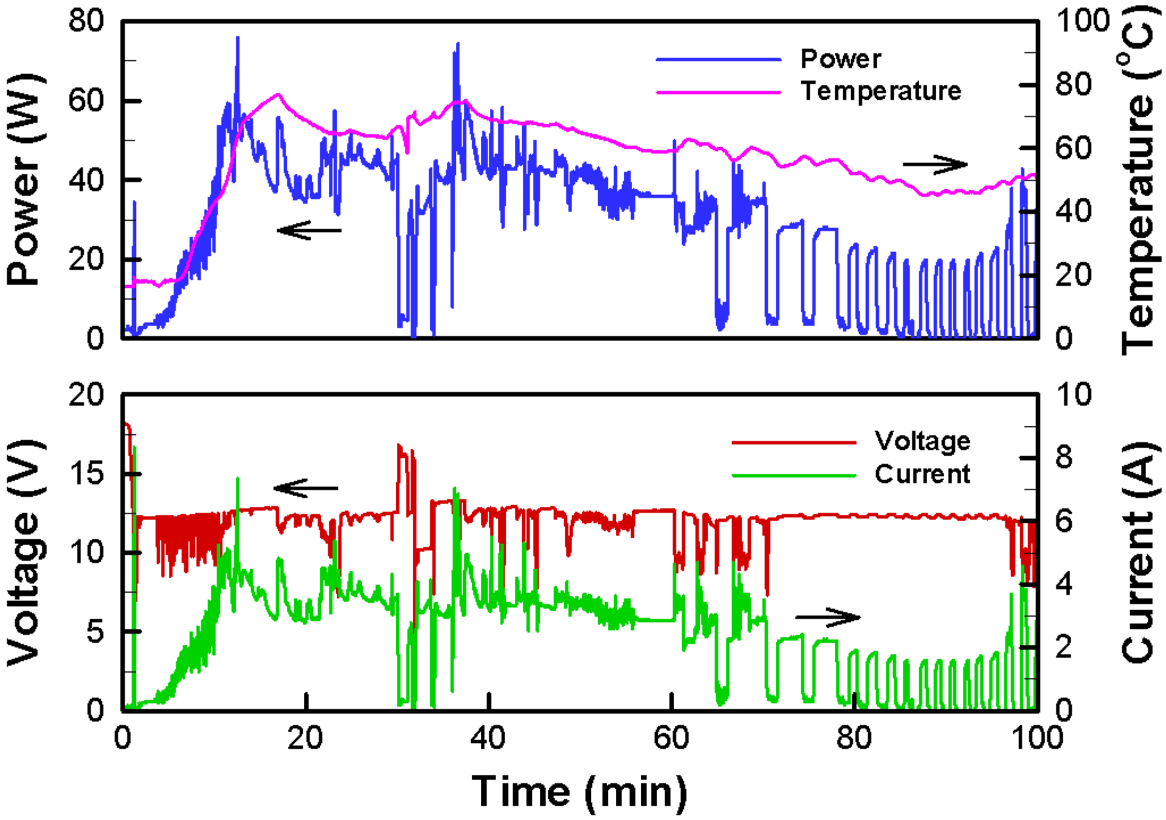

Fig. 3 Power output and temperature of the fuel cell system during the flight test

4. CONCLUSIONS

The design, construction, and flight test results of a fuel cell-powered small unmanned aircraft were described in this paper. The demonstration aircraft was designed taking performance characteristics and loading volume of the fuel cell system into consideration. The fuel cell system consisted of a fuel cell stack and a hydrogen generator, which produced hydrogen using a catalytic hydrolysis reaction from NaBH4 alkaline solution. The fuel cell system was integrated into the fuselage and the flight tests of the fuel cell aircraft were successfully carried out.

ACKNOWLEDGEMENTS

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