High Efficiency Fuel Cell Stack and Key Technologies of Power Module

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Abstract. In this paper, the development of key technologies in fuel cell stacks and fuel cell power modules are reported, with emphasis on high-volume production (>10,000 units/year). Fuel cell stack design is focused on the development of high-efficiency membrane electrode assemblies ($\geqq$300 mA/cm^2 @0.8 V) suitable for continuous roll-to-roll manufacturing and high volumetric efficiency stacks (1.5 kW/L) with power rating of at least 10 kW. Power module design focuses on the union of liquid-cooled fuel cell stack, smart power conditioning technology, battery, hydrogen storage system and balance-of-plant into a fully-integrated, drop-in unit for MHE (Material Handling Equipment) systems. Technical verification was conducted by integrating the fuel cell power module into an automated guided vehicle as a turn-key replacement for the original power system. Power module performance was demonstrated with continuous current loading up to 240 A and peak current loading of 300 A. All core technologies of the fuel cell power module are deliverable as a free-standing total solution, expanding the potential applications beyond vehicle systems, and allowing rapid commercialization of related technologies.

Keywords: Fuel cell stack · Fuel cell power module · Material handling equipment · Turn-key replacement

1 Introduction

1.1 Technology Overview

This article reports on the technology of integrating fuel cells with secondary batteries and balance-of-plant components into a fuel cell power module for the material handling industry. The proton-exchange membrane fuel cell (PEMFC) is a well-researched and proven technology for a wide range of operating conditions. The BoP can be divided into three sub-systems: anode, cathode, and coolant. The anode sub-system includes hydrogen storage, re-circulation, and purging components. Hydrogen is compressed to 5000 PSI and is stored in an onboard tank. Re-circulation and purging are closely related,

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where unconsumed hydrogen is recycled to the fuel cell stack inlet after excess water is separated and, along with other unwanted inert chemicals, is purged from the anode sub-system. The cathode sub-system includes air humidification and heat exchange components with the purpose of delivering humidified air to the fuel cell stack. The coolant sub-system is comprised of the thermal management components including coolant pump, fan, and radiator. Selection criteria for BoP components is intimately connected to fuel cell stack design and intended operating conditions, in addition to the cost and availability considerations discussed in the next sub-section.

2 Fuel Cell Stack and Power Module

This section introduces the key components of the fuel cell stack and the power module. Special emphasis is placed on the electro-chemical performance of the stack under different operating conditions. Since the power module consists of a fuel cell stack and a lithium-ion battery pack, the interaction between these two power sources during the operation of the propulsion system was also carefully examined.

2.1 Membrane-Electrode Assembly

The quality of the MEA design will affect the catalyst-use efficiency in the electrode, the flow rate requirements of fuel and air, the uniformity of current distribution, and the level of discharge efficiency.

The catalyst and the binder are uniformly coated by mixing and dispersing technology, and a highly dispersible catalyst slurry is prepared. Through the catalyst coating technology, the reaction triple phase boundary required for fuel cell reaction is constructed. The use of catalyst-coated membrane (CCM) continuous processing technology, such as Roll-to-Roll manufacturing in Fig. 1, greatly shortens the tedious batch processing time, improves the yield and increases the effective utilization of catalyst.

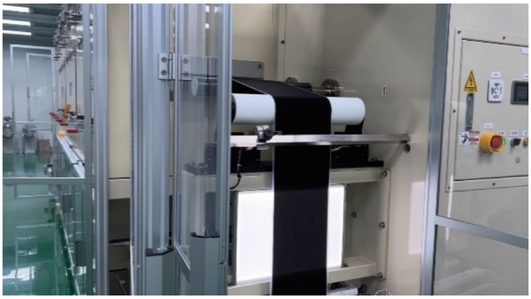

Fig. 1. CCM roll-to-roll manufacturing

This article exhibits a liquid-cooled fuel cell operating at 70 °C, referring to the DOE standard ($\geqq$300 mA/cm^2 @0.8 V) [1] for high-powered MEAs. The MEA was tested with reactant stoichiometry of 1.5X and 2.5X for hydrogen and oxygen, respectively.

A 5000-h constant current discharge mode life test has been completed. Under the discharge of 300 mA/cm^2, the $\Delta V/V$ performance of the MEA declined by 0.15%, and under the discharge of 360 mA/cm^2, the $\Delta V/V$ performance of the MEA declined by 2.55%, verifying the lifespan of the high-power MEA ≥5000 h, as shown in Fig. 2 performance-time graph.

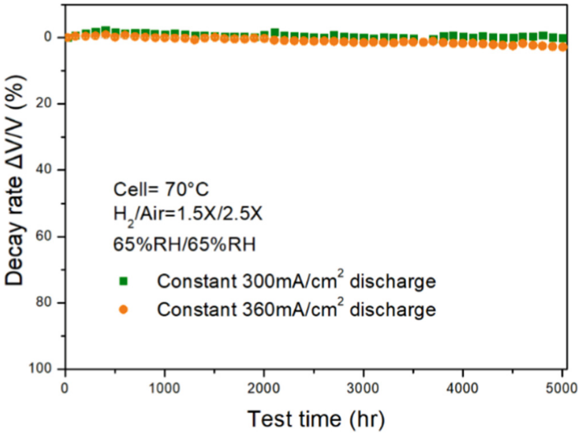

Fig. 2. Performance decay-time graph for MEA at 5000 h

2.2 Fuel Cell Stack

The design of a high-efficiency liquid-cooled fuel cell stack was based on the experience and assembly mechanism of existing traditional fuel cell stack designs. The requirements of the target industry include both the power requirements (≥10 kW) and the volume power density requirements of material handling vehicles and after testing three full-sized liquid-cooled fuel cell stacks were assembled for demonstration purposes (Fig. 3), to determine optimal stack operating conditions (Table 1), each fuel cell stack was activated through repeated current load cycling until maximum performance was achieved. The highest performance record measured by I-V curve is 12.5 kW (250 Amps @ 50 V) at the stoichiometric ratio of 1.2 and 2.0 for anode and cathode, respectively (Fig. 4). Using the measured stack volume (8.24 L) [2], the power volume density is 1.51 kW/L.

2.3 Fuel Cell Power Module

The fuel cell power module is mainly divided into five major items: liquid-cooled fuel cell stack, thermal management module, cathode air humidification module, hydrogen storage and delivery module, and energy storage module (Fig. 5).

Before assembling into a power module, each subsystem was assembled on a test bench for BoP component validation testing. The test bench is equipped with control boards, user interface, load banks and other testing equipment (錯誤! 找不到參照來

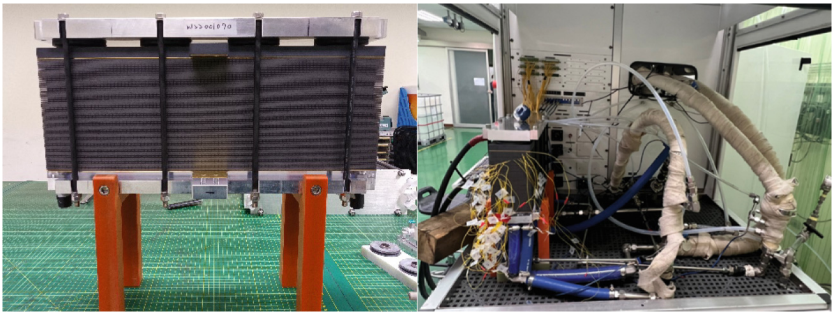

Fig. 3. Full-sized fuel cell stack and testing equipment

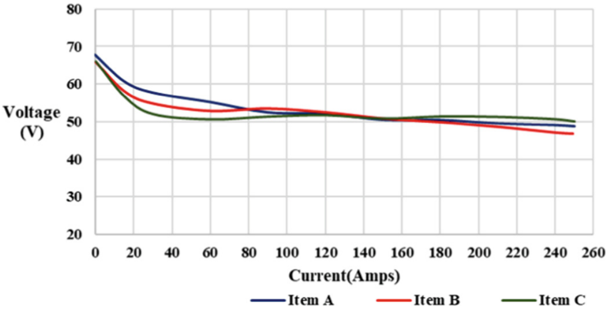

Fig. 4. Fuel cell stack performance curves

Table 1. Fuel cell stack operating parameters

	Item	Stoichoimetry	Temp./RH
Anode	A	1.5	65 °C/100RH%
	B	1.5	70 °C/50RH%
	C	1.2	70 °C/50RH%
Cathode	A	3	65 °C/100RH%
	B	3	70 °C/50RH%
	C	2	70 °C/50RH%
Coolant	A	–	65
	B	–	70
	C	–	70

源。). The operating conditions of the power module system was simulated on the test bench through the user interface designed specifically for testing the system control. Various fuel cell stacks and BoP components were tested before deciding on the final BoP configuration. Once the whole system was tested and confirmed cooperating with

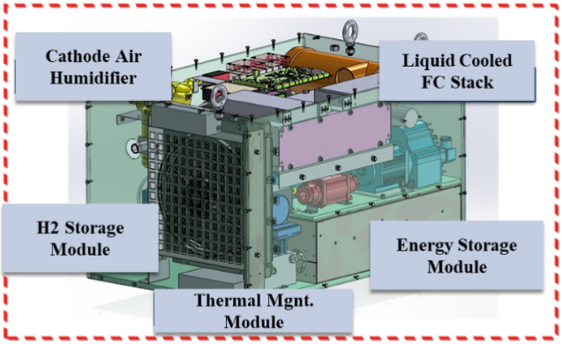

Fig. 5. Schematic diagram of the five major modules of a fuel cell power module

each other, functional stability tests, as shown in (Fig. 7), were conducted for tuning system-wide parameters. During the system testing, it was confirmed that the module can reach 10.6 kW net power, meeting the target design requirement for the material handling equipment AGV market needs (Fig. 6).

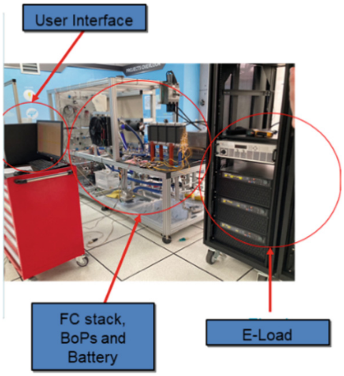

Fig. 6. Fuel cell stack with BoP components and battery on test bench

3 Power Module and AGV

The composition of the AGV system mainly includes two parts, namely the control system and the basic hardware. Furthermore, the control system can be mainly divided into the management and monitoring system, the vehicle controller and navigation system; the basic hardware mainly includes chassis, locomotion drivers, sensors, power units (secondary batteries or fuel cells), shelves, docks, network equipment and other parts. In order to complete the relevant technical verification, it is planned to integrate the power module into a commercial unmanned vehicle to replace the original secondary battery module. Integration includes not just the power module, but also a hybrid power control system, AGV system peripherals, and auxiliary components as shown in Fig. 8.

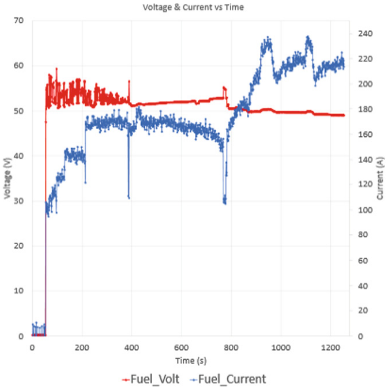

Fig. 7. System performance test output graph

During the integration and testing, empirical data will be collected, and a complete layout of the integration interface between the power module and the transport vehicle system will be developed. Once the integration interface is fully developed, the application of fuel cell power modules is planned to be extended to other products, and related technologies can be commercialized.

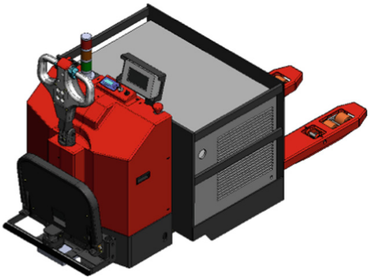

Fig. 8. AGV system with FC module

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