Sea experiment of a survey AUV powered by a fuel cell system

E. RAUGEL, HELION AREVA
V. RIGAUD, IFREMER
C. LAKEMAN, AREVA RENEWABLE

Introduction

The use of autonomous underwater systems, such as AUV, is currently limited by their on board energy supply. The emergence of a higher capacity power source could be a breakthrough that extends these technologies field of application.

Since 2005, within the PACSM project[1], fuel cell systems for underwater applications were studied. HELION, an AREVA Renewable subsidiary, dedicated to both PEM fuel cell and electrolyze systems development, has designed a fuel cell system adapted for AUV energy supply, for integration on IFREMER survey AUV, called IDEF^{X}.

This technology interest for underwater power source has already been proven by several experiments. For example, the URASHIMA propelled by a fuel cell system, performed 317 km long-distance continuous nonstop cruise. PACSM project objective is not only the development of a new prototype, but also to test its sea operational implementation. During sea experiments in October 2009, the AUV did 7 dives, with gas refill on the ship before each dive.

The fuel cell system

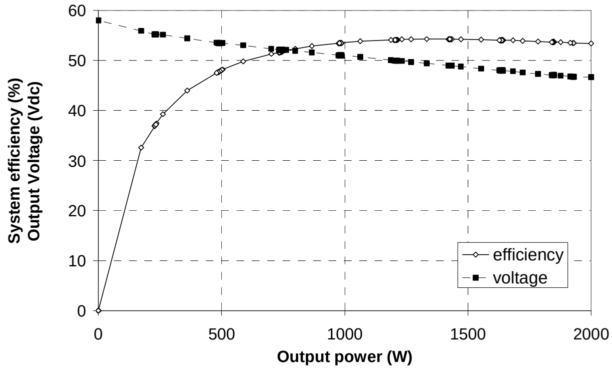
A typical fuel cell is an electrochemical conversion device where gaseous hydrogen and oxygen are combined catalytically to produce water, heat, and useful electricity. Hydrogen fuel is fed into the fuel cell anode and oxygen (or air) enters the cathode. Using a catalyst hydrogen atom splits into a proton and an electron which take different paths to react at the cathode. Ions created by the reactions flow through the electrolyte between the two electrodes and an external current can be generated by closing the circuit. The combination of hydrogen and oxygen forms a molecule of water. This reaction in a single fuel cell produces from 1 volt (no current) to 0.7 volts at full rated load. To deliver the desired amount of power, cells are combined in series in a fuel cell stack. A fuel cell system is composed of a fuel cell stack, gas storage, gas management subsystem that supplies fuel cell with H_2 and O_2 and evacuates produced water, a cooling subsystem, and the power conditioning.

The main difference with batteries is that in a fuel cell, energy is supplied continuously by converting external sources of fuel and oxidant, while a battery stores its energy internally. So fuel cell autonomy depends only on gas storage capacity. Most of the fuel cell systems for terrestrial applications use oxygen extracted from ambient air. For underwater application, the fuel cell must be supplied with pure hydrogen and pure oxygen.

The fuel cell stack developed in this study is composed of 63 cells, based on PEM technology. It was designed to give the nominal power directly at the voltage level needed by the AUV, with high efficiency to minimize gas storage volume. In this way, it produces 1.5 kW at 48Vdc and system efficiency (including auxiliaries' consumption) is around 55%. Fuel cell gas management is based on re-circulation of both hydrogen and oxygen gases. It allows the full conversion of the reactants, as no purge is needed during underwater operation. Excess hydrogen and oxygen move trough the stack, carrying the water with them; gases are separated from the water and recirculated. The water is collected in a tank inside the system in order to keep a constant mass of the AUV.

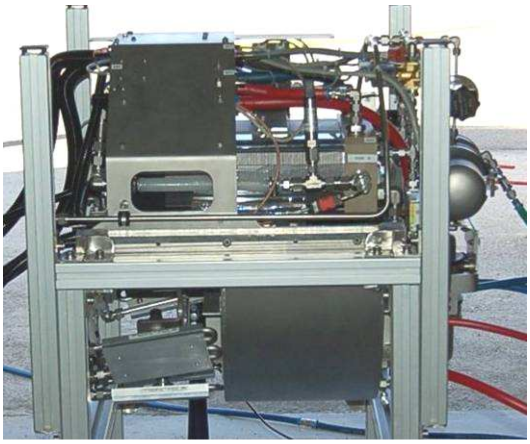
---

[1] PACSM project :
- Subsidized by ANR (Agence Nationale pour la recherche, France)
- Consortium : HELION, IFREMER, ECA, CYBERNETIX, SNPE matériau énergétique, ARMINES CEP

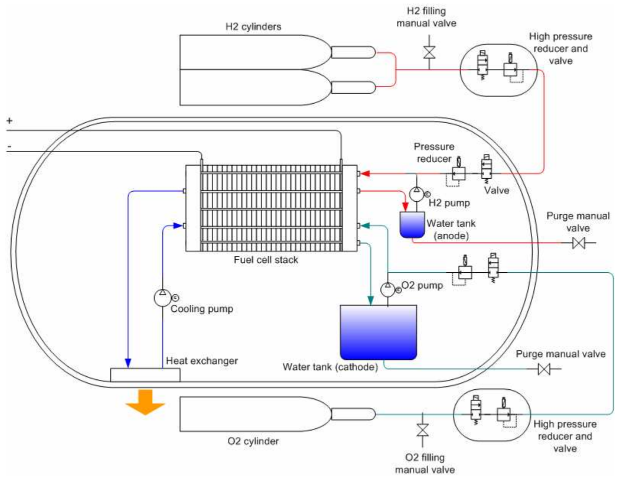


Fuel cell system performance

The fuel cell system is a closed-cycle system integrated in an aluminium pressure vessel that resists the external pressure, similar to the AUV vessel that contains batteries and controller. The container is pressurized with nitrogen so that the fuel cell is operated in an inert atmosphere, preventing gas leaks and an explosive mixture of hydrogen and oxygen.
The PEMFC operates at low temperature (around 70℃), that is maintained by a cooling loop, circulating though the stack. The heat exchanger is flattened against the vessel, to dissipate heat into the sea.

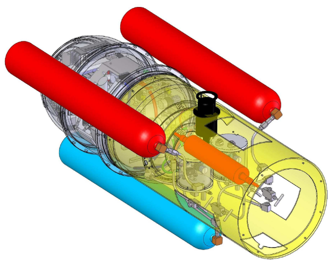


Fuel cell system without pressure vessel



Block diagram of the fuel cell system

The reactants are stored in the conventional 50 litres steel cylinders: two cylinders pressurized at 300 bars of hydrogen, and one pressurized at 250 bars of oxygen. This storage provides an electrical capacity of 36 kWh to the fuel cell system.
During operation, the reaction consumes gas and produces water; there is a mass transfer from gas storage to water tank inside fuel cell system. Cylinders are located around fuel cell vessel in order to maintain both the centre of gravity and a good AUV equilibrium.
The fuel cell system and H2-O2 storage can be considered as an additional section that can be easily integrated in the AUV. The additional mass is around 800kg, and the additional length is 1.5 meters.



Power	0 to 2kW 1.5 kW at 48Vdc
Gas storage capacity	H2 : 100litres at 300 bars O2 : 50 litres at 250 bars
Autonomy	36 kWh
Mass	800 kg
Lenght	1.5 m
maximal depth	800m (limitation due to gas cylinders)

Fuel cell system characteristics

In standard configuration, AUV IDEF^{X} is equipped with 10kWh lithium ion batteries. Using fuel cell technology increases the autonomy up to 46kWh. In this configuration, the AUV has a mass of 1600kg, and is 6 meters in length.

Sea experiment

A first validation of this system was done in a pool. We operated the fuel cell with different loads to ensure a good overall performance of the system. In October 2009, we ran a sea experiment to improve the system in operational conditions, working from a ship.
The AUV did 7 dives, with different mission profiles, at a maximal depth of 400m. Despite its additional mass and structure modifications, the AUV showed good maneuverability and the manipulations remained easy during launching and recovery phases.
Before each dive, we refilled the AUV with hydrogen and oxygen from standard bottle racks pressurized at 200 bars carried on board the ship. The gas transfer was done using H_2 and O_2 refuelling compressors plugged directly into the AUV. This operation is quicker than the charging of a battery (less than one hour for both gases). After each dive, the fuel cell was stopped, and the waste water was purged. All of those procedures are very simple and limited to only the opening and closing of manual valves. Hydrogen and oxygen losses during those operations were minimized, so that the fuel system could be operated safely.



Conclusion

The fuel cell system developed in this project is easily to operate and thus is a power source useful in underwater applications. We had to adapt it to an existing AUV. So it was difficult to fully optimize the integration, especially because the fuel cell system was in a separate vessel. Mass and volume can be largely improved if fuel cell constraints are taken into account at the start of the AUV conception.
At the end of this year, another experiment using the fuel cell system will be performed, this time the hybridization with Lithium-ion batteries will be evaluated. The electrical energy required on board will be provided by the fuel cell and will be buffered via batteries, capable of supplying peak power. Those tests will be done with the company ECA, coupling the fuel cell system to the AUV ALISTAR3000, in order to validate a power conditioning adapted to high dynamic load profiles.
Fuel cells are an innovating power source for underwater propulsion (AUV, submarine) but they could also be used in stationary applications such as benthic station energy supply or backup power for subsea equipment. Moreover, this technology can be applied to any kind of harsh environment.

Reference

[1] Toshio MAEDA, *Fuel cell AUV “URASHIMA”*, Mitsubishi Heavy Industries, Ldt. Technical Review Vol.43 n°1 (January 2006)