

Yokosuka Cruise Report
YK11-02

Sea Trial of The HETL Fuel Cell System for
Underwater Platform

JAMSTEC ~ Sagami-Bay ~ JAMSTEC

March 6, 2011 ~ March 9, 2011

Japan Agency for Marine-Earth Science and Technology
(JAMSTEC)

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1. CRUISE INFORMATION

- ✓ Cruise number: YK11-02
- ✓ Ship name: Yokosuka
- ✓ Title of the cruise: Sea trial of the HETL fuel cell system.
- ✓ Title of proposal:
Development of the next generation underwater vehicle technology
- ✓ Cruise period: March 6, 2011 ~ March 9, 2010
- ✓ Port call: JAMSTEC ~ Sagami-Bay ~ JAMSTEC
- ✓ Research Area: Sagami Bay
- ✓ Research Map:



Fig. 1. Sagami-Bay

2. RESEARCHERS

<u>Name</u>	<u>Affiliation</u>	<u>Assignment</u>	<u>Remarks</u>
Hiroshi Yoshida	Maritec, JAMSTEC	General management	Chief Scientist
Tadahiro Hyakudome	Maritec, JAMSTEC	Management asistant	Science party
Makoto Sugawara	Maritec, JAMSTEC	Engineering	
Naohito Mori	Marin Work Japan	Technical supporting	
Toshihiro Tani	Mitsubishi Heavy Industry	FC Engineering	Engineers
Mitsuyoshi Iwata	Mitsubishi Heavy Industry	FC Engineering	
Takahiro Kimura	Mitsubishi Heavy Industry	Technical supporting	

3. SEA-TRIAL

3.1 Background and objectives

JAMSTEC conducted a research and development project for a next generation autonomous underwater vehicle (AUV) as a part of “Key Technologies of National Importance” from 2006 to 2011. The goal of the project was to develop an AUV with the ability to cruise long range over 3,000 km and carry large payloads for surveys of natural resources, improvement of earthquake predictions, and for environmental research.

To perform underwater survey and exploration efficiently, autonomous underwater platforms which can be equipped with lots of sensors are suitable. Cutting edge underwater platforms or underwater vehicles have capability for surveys in the vast underwater environment. Increasing survey range of a platform makes an increase of the consumption energy. High power sensors such as a deep-sea seismic system or an active electric field sensor also consume much energy. We chose a compact underwater fuel cell (FC) system as a better solution for wide range surveys and for high power sensors.

An underwater FC would run on pure-hydrogen and pure-oxygen due to consisting of a closed cycle system. The water reacted in the FC should be stored in the vehicle body to keep its buoyancy constant. We have thus developed a completely isolated FC system from external ambient, which confines gases and reactant water to the system, named the closed-cycle PEFC (Proton-Exchange membrane FC) system. The first PEFC system consisted of two stacks, recirculation blowers, humidifiers, a metal hydride vessel, a high-pressure oxygen tank, and a water storage tank generating power of 4 kW. The whole devices were installed into a titanium pressure vessel. The maximum FC efficiency was

about 54 % at typical cruising speed. The AUV, Urashima (10 m, 10 tons), is the first prototype of FC underwater vehicle equipped with the closed-cycle FC system. This vehicle set a world record of cruising distance of 317 km in 2005.

The second FC system must achieve the efficiency of over 60 %, downsizing compared with the first one, reducing consumption power on the auxiliaries, and large endurance up to 600 hours. We developed a desktop model named HETL (High-Efficiency Three-Less) FC which is characterized by discarding gas recirculation blowers and humidifiers and reducing hydrogen leak (leak-less) from 2006 to 2009. From 2010 we developed the first prototype of the HETL FC system to be carried out sea-trials.

In this article, we report sea trial results of the HETL prototype.

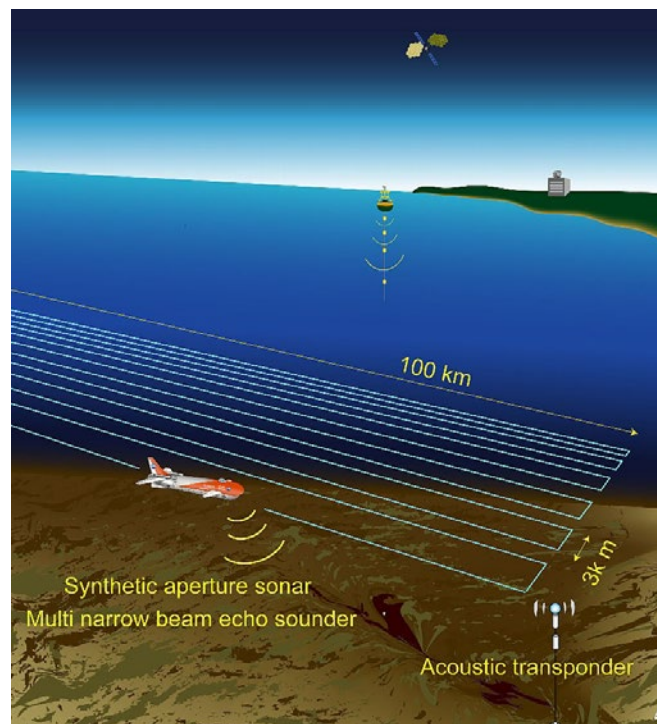


Figure 3.1.1. An image of underwater resource exploration with an AUV

3. 2 The HETL fuel cell system

1) Operating principle of the HETL fuel cell system

The operating principle of the HETL FC system is shown in Figure 3.2.1. To help the reader to understand, the figure only shows oxygen lines. The system consists of two stacks (A stack and B stack), four valves (#1 to #4), and two liquid separators.

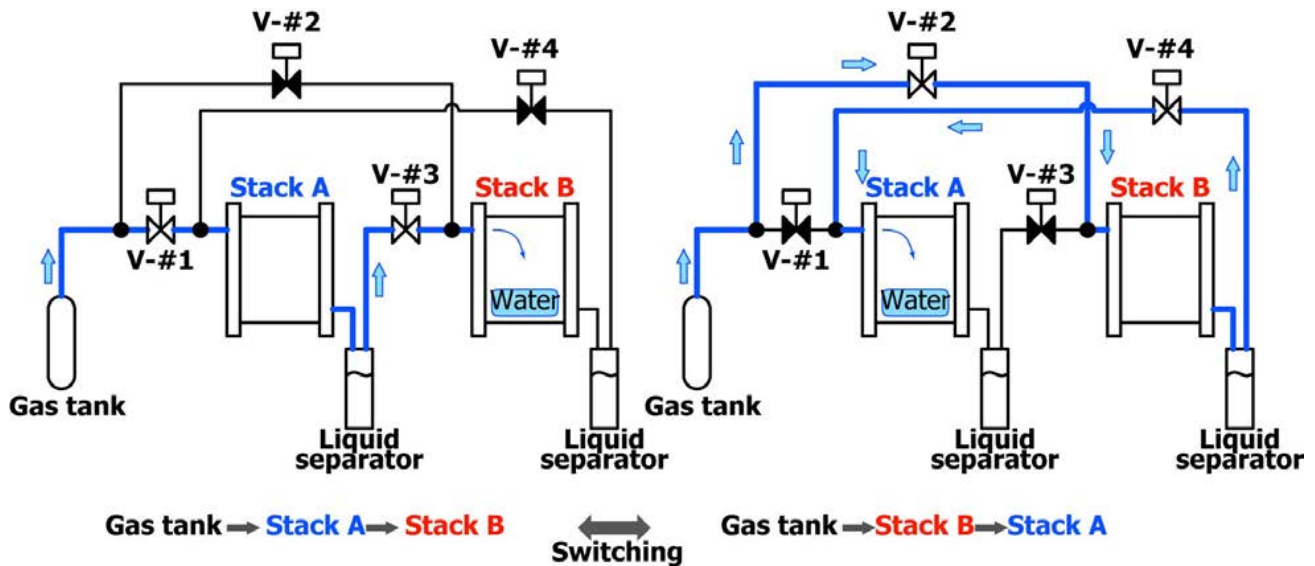


Figure 3.2.1. The HETL fuel cell principle.

Reactant gas is, first, supplied to the upper stream stack (stack A) when the V-#1 and the V-#3 are opened and the V-#2 and the V-#4 are closed. At this time, the surplus gas (50% utilization) is supplied to the lower stream stack (stack B). All gas is thus consumed. The water generated by reaction is accumulated in the stack B. In the next phase, the V-#1 and the V-#3 must be switched from open to close and the V-#2 and the V-#4 are opposite before voltage in the stack B to be reduced by the water. The water accumulated in the stack B is, then, exhausted out to the liquid separator by gas supplied directly from the tank. By repeating this switching process, generating water can be ejected from the both stacks even if there is no gas circulation blower. The mechanical action and state of the HETL fuel cell system is listed in Table I.

Table I. State of the system and the devices in the both phase.

Phase	V#-1&3	V#-2&4	Stack	Gas from the tank	Generated Water
1	Open	Close	A	directly supplied	ejected
			B	humidified by A	accumulated
2	Close	Open	B	Directly supplied	ejected
			A	humidified by B	accumulated

2) A prototype development

In 2010 we designed the prototype model and tested the stacks developed. Its specifications are below:

Dimension : I.D. 600 × 900(L) mm

Weight	: 300 kg in air
Power	: 300 W / 24 V
Operation	: Standalone, N ₂ purge less
Fuel/Oxidant	: External pure H ₂ and O ₂

The HETL FC prototype consists of major three parts: a fuel cell section, an electronic controller, and a pressure-tight housing. The fuel cell section consists of two 150 W-stacks, electrically controlled valves, sensors, and liquid separators. All devices are mounted on a chassis. The Fuel Cell reaction component occupies 70% of the pressure hull capacity. The remaining space is assigned to the electrical component. The system block diagram is shown in Figure 3.2.2.

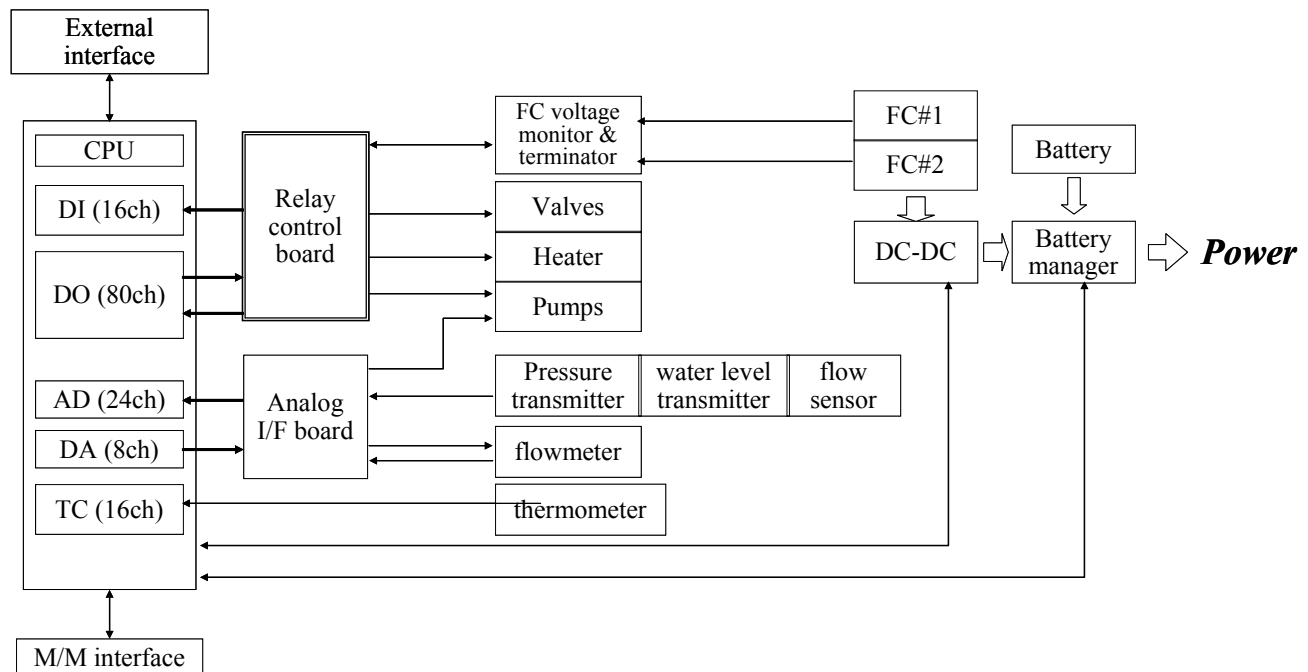


Figure 3.2.2 Blockdiagram of the HETL FC prototype.

A photo of the prototype model set in a transparent case is shown in Figure 3.2.3. Current versus voltage curves (I-V curves) measured are shown in Figure 3.2.4. Red line denotes of the prototype. Green and pink lines denote of Urashima and of the desktop-model which was previously developed, respectively. In operating range (0 A ~ 20 A), the cell performance of the prototype model are equal to of the desktop-model. The time trend in change of the cell voltage is shown in Figure 3.2.5. Load current and output voltage are constant under background pressure of 400 kPa abs. In this test, the switching is repeated every two minutes (four minutes for one-cycle).

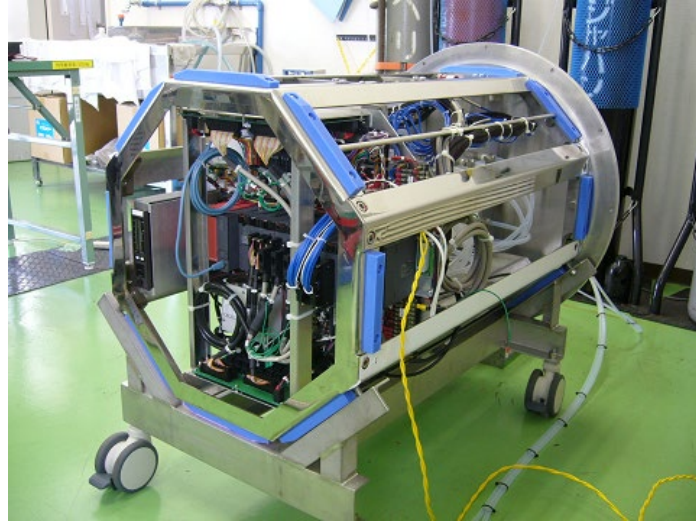


Figure 3.2.3. A snap shot of the prototype model displayed

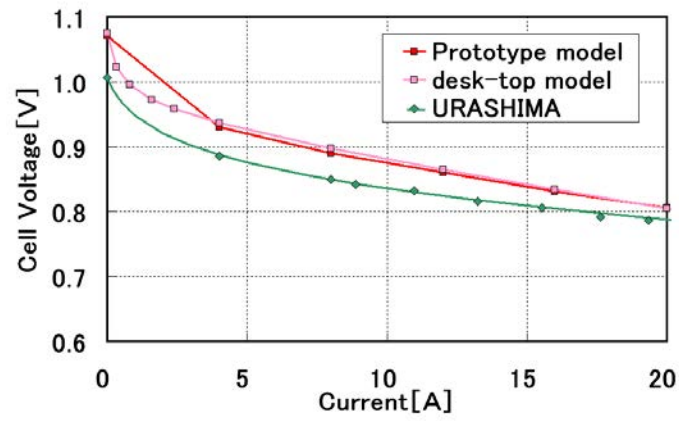


Figure 3.2.4. I-V curves measured.

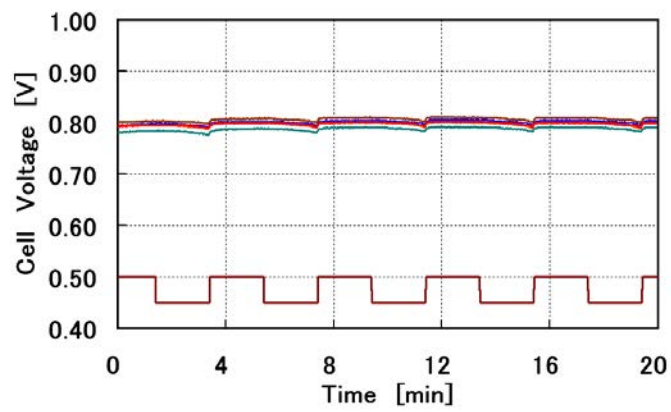


Figure 3.2.5. Time trend of the cell voltage

3) The Deep-tow equipped with the HETL fuel cell system

Then, we put this prototype model into a pressure vessel, and it was combined with gas cylinders and regulators to carry out a sea-trial. We constructed the total system which consists of a deep tow, a winch-cable system, a ship-side system and a ship-side controller as figured in Figure 3.2.6 and in Figure 3.2.7. The deep tow is equipped with a main pressure hull ($\phi 700 \times 920$ mm) including the HETL FC, two 10 liters gas tanks (H_2 and O_2), communication pressure hull, a battery pressure hull, and payloads (a camera and two 100 W halogen lights). The ship-side system supplies gases (i.e. nitrogen) and water to the HETL system on the deck and is used to shutdown the FC for long-time period. The ship-side controller consists of an optical communication system, the HETL FC controller/monitor, and the payload controller.

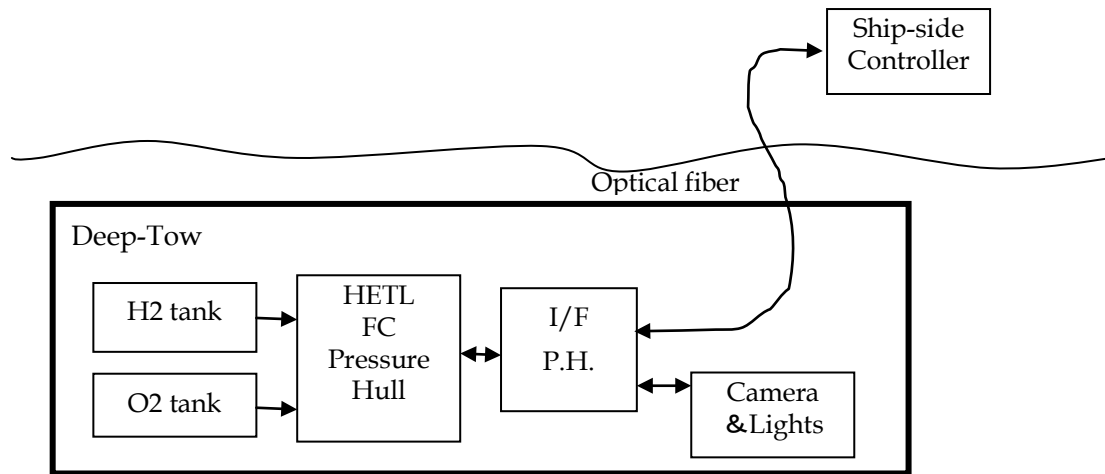


Figure 3.2.6. Block diagram of the FC deep tow.

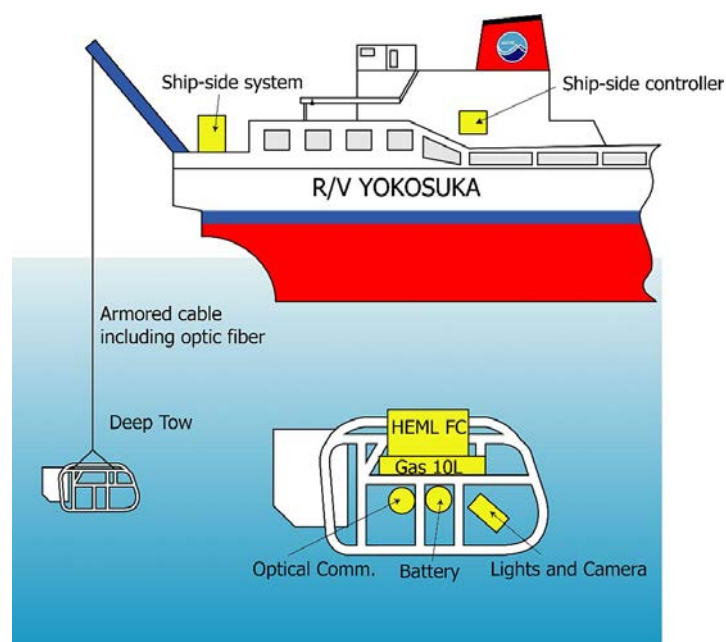


Figure 3.2.7. Test configuration of the sea-trial with the R/V Yokosuka

3.3. Results

We carried out a sea-trial of the HEML FC system in March 2011. A snapshot taken during sea-trial is shown in Figure 3.3.1. At this sea-trial, we started the HETL FC system in the sea. The halogen lights were turned on and off by signal from the ship-side controller, and stack voltages changed in response to load changes. During sea-trial, the stack voltages had been vary stable, we completed this trial successfully.



Figure 3.3.1. A snapshot when the deep tow equipped with the FC system is retrieving.

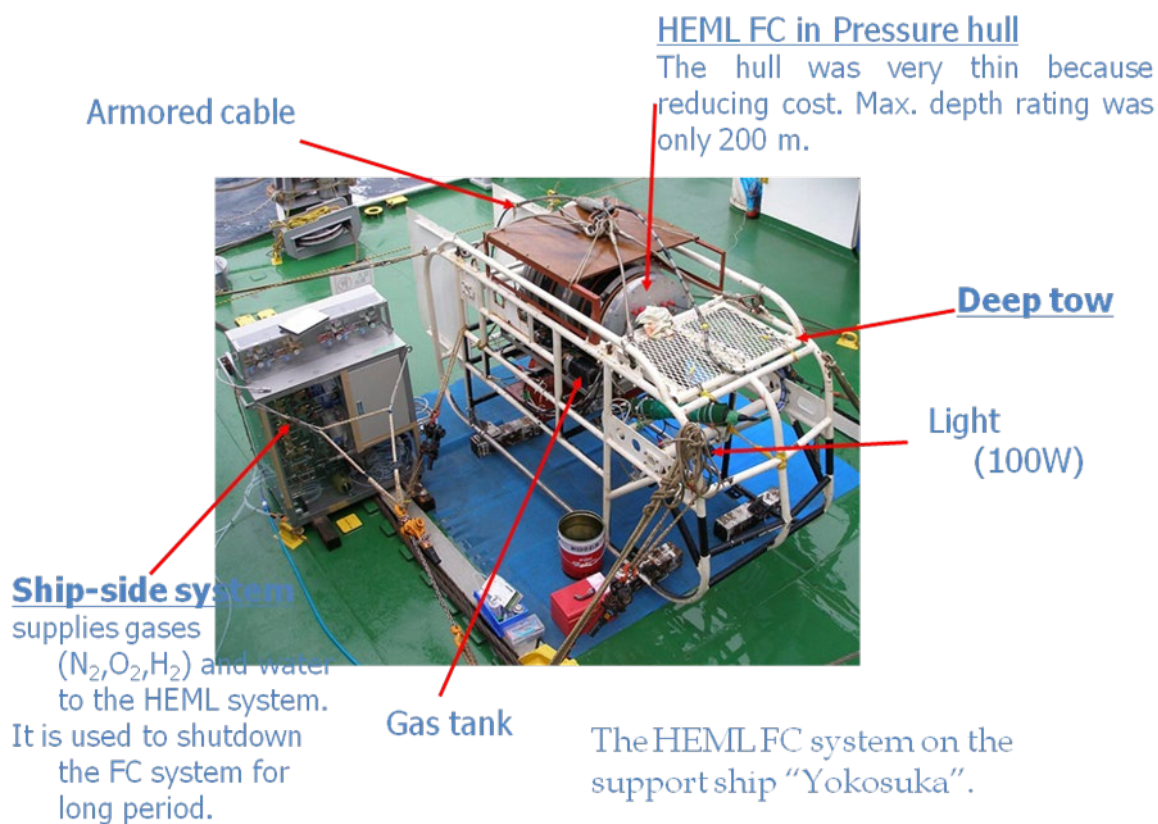


Figure 3.3.2. The HETL fuel cell on the deck.

1) Schedule

Date	Area	Operation
March 6, 2011	Pier of JAMSTEC	Loading departure Adjustment of the fuel cell
March 7	Sagami Bay	Booting the system Descent to 100 m System failed at depth of 100 m
March 8	Sagami Bay	Booting the system Descent to 130 m Manual valve was failed System rebooting at 100 m
March 9	Pier of JAMSTEC	Arrival in the JAMSTEC port Unloading

2) The First dive

i. Maximum depth dove: 100 m

ii. Diving time: 2 hours 2 minutes

iii. Test items

- ✓ Test on the deck #1 (The FC was fueled by gas tanks on the deck)
- ✓ Underwater operation test #1

iv. Detail

- ① The FC was supplied O₂ and H₂ gas on the deck.
- ② Checked full load current, voltage, and power. (I = 42.9 A, V = 9.41 V, P = 403.6 W)
- ③ Kept an OCV status and landed in the sea.
- ④ Turned on the lights at depth of 30 m. (I=15.9A, V=5.4 V, P=85.9W)
- ⑤ Descent to 100 m with lighting on.
- ⑥ Switched on/off at depth of 100 m.
- ⑦ The Battery voltage rapidly decreased in an hour.
- ⑧ Turned off the lights by remote control and ascent the deep tow.
- ⑨ Shut down the system on the deck.

There was no damage in the fuel cell system.

Figures 3.3.3 and 3.3.4 show an I-V curve and an I-V time trend measured, respectively.

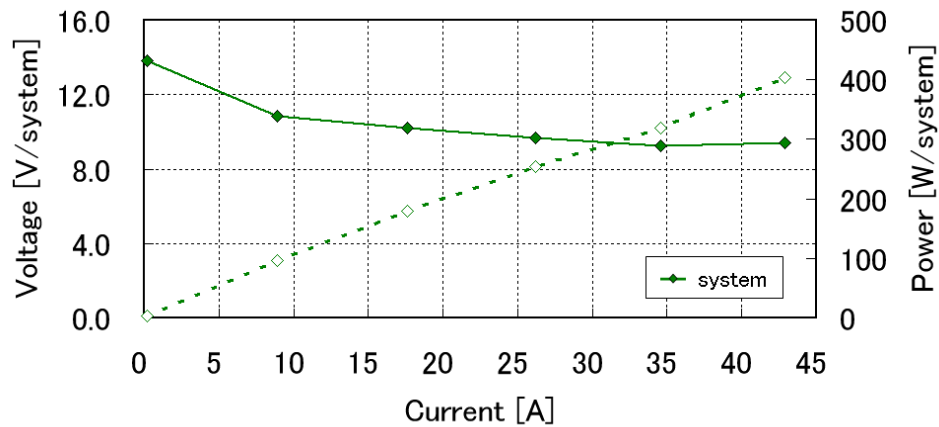


Figure 3.3.3. I-V curve obtained in the 1st dive.

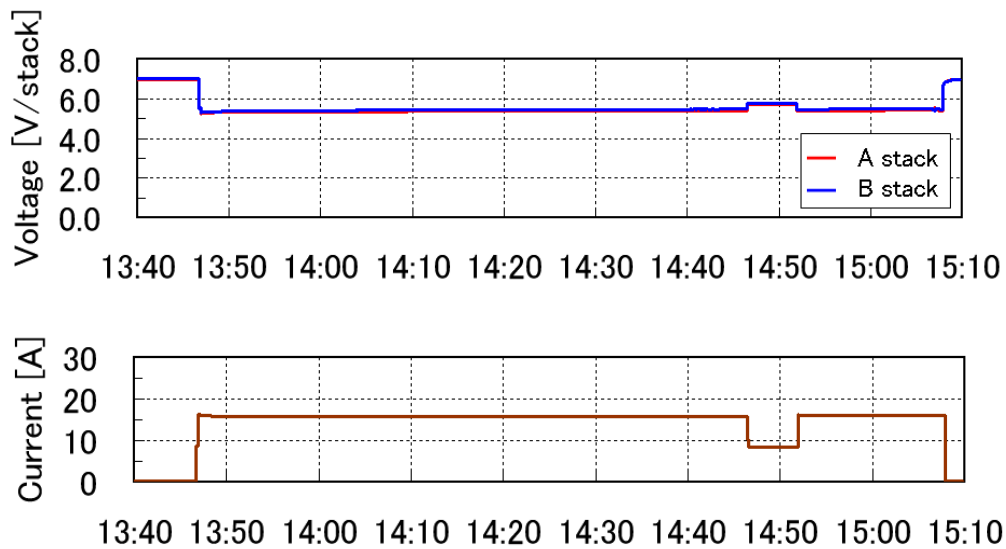


Figure 3.3.4. Time trend of voltage and current recorded in the 1st dive.

3) The Second Dive

i. Maximum depth dove: 130 m

ii. Diving time: 1 hour 50 minutes

iii. Test items

- ✓ Test on the deck #2 (The FC was fueled by gas tanks on the deep tow)
- ✓ Underwater operation test #2

iv. Detail

- ① The FC was supplied O₂ and H₂ gas on the deck.
- ② Checked load current, voltage, and power. (I = 34.6 A, V = 8.96 V, P = 310 W)
- ③ System status was changed to stand-by. (This is not an OCV status)
- ④ Kept the stand-by status and landed in the sea.

- ⑤ Descent to the depth of 100 m.
- ⑥ Activated the system to generation status.
- ⑦ Turned on the lights. ($I=15.9\text{A}$, $V=5.4\text{ V}$, $P=85.9\text{W}$)
- ⑧ Descent deeper.
- ⑨ A system failure was occurred at 115 m.
- ⑩ Stand-by the system and ascent to 50 m.
- ⑪ Rebooted the system and lights on.
- ⑫ A system failure was occurred again at 115 m.
- ⑬ Turned off the lights by remote control and ascent the deep tow.
- ⑭ Shut down the system on the deck.

There was no damage in the fuel cell system.

Figures 3.3.5 and 3.3.6 show an I-V curve and an I-V time trend measured, respectively.

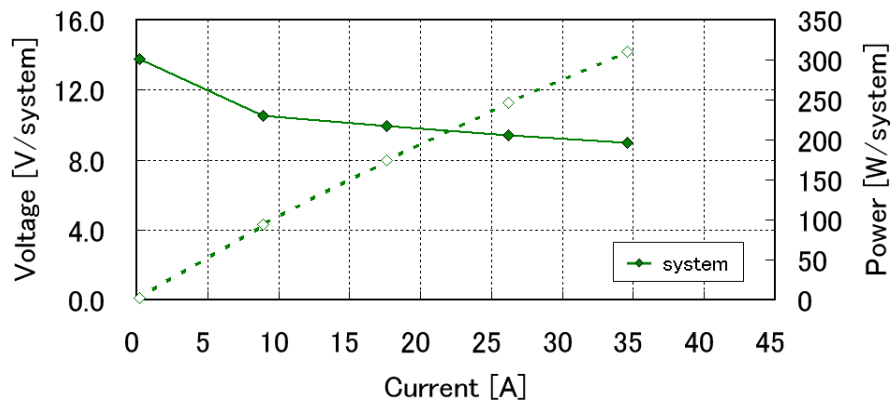


Figure 3.3.5. I-V curve obtained in the 2nd dive.

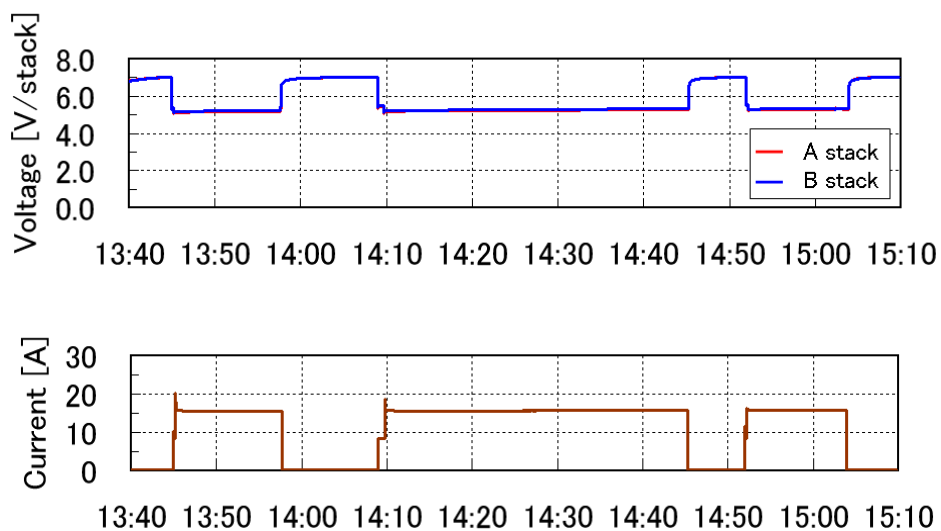


Figure 3.3.6. Time trend of voltage and current recorded in the 2nd dive.

4) Bugs

We found some bugs in the sea trial as below.

- i. failure of the pressure transducers
- ii. failure of one of the manual valves
- iii. Over discharging of the internal lithium ion battery.

The bugs of #i and # ii are not serious due to low cost design. The devices used are not special for deep sea operation. One of manual valves used was not stable. It was closed over depth of 130 m. We already developed specials for Urashima using additional pressure hull and tested in sea trials. These bugs were, thus, solved.

The bugs of #iii results from our circuit design. The battery circuit used did not automatically select a battery charging status. It acts only manually. In the test, battery was not charged because we did not recognize it. We modify the circuit to discard this failure till the next test.