C1PoJ-03

KOBE UNIVERSITY

Iwatani

NIMS 国立研究開発法人 物質・材料研究機構 National Institute for Materials Science

The 2017 Cryogenic Engineering Conference and International Cryogenic Materials Conference, Monona Terrace in Madison Wisconsin July 9-13, 2017

First experiment on liquid hydrogen transportation by ship inside Osaka bay

K Maekawa[1], M Takeda[1], T Hamaura[1], K Suzuki[1], Y Miyake[1], Y Matsuno[2], S Fujikawa[2] and H Kumakura[3]

[1] Kobe University, Kobe, Hyogo 658-0022, Japan

[2] Iwatani Corporation, Amagasaki, Hyogo 661-0965, Japan

[3] National Institute for Materials Science, Tsukuba, Ibaraki 305-0047, Japan

takeda@maritime.kobe-u.ac.jp

A project to import a large amount of liquid hydrogen (LH_2) from Australia by a cargo carrier, which is equipped with two 1250 m^3 tank, is proceeded in Japan. It is important to understand sloshing and boil-off characteristics inside the LH_2 tank during marine transportation. However, the LH_2 sloshing and boil-off characteristics on the sea has not yet been clarified. First experiment on the LH_2 transportation of 20 liter with magnesium diboride (MgB_2) level sensors by the training ship "Fukae-maru", which has 50 m long and 449 ton gross weight, was carried out successfully inside Osaka bay on February 2, 2017. In the experiment, synchronous measurements of liquid level, temperature, pressure, ship motions, and accelerations were done. Experimental results of the LH_2 sloshing and the rapid depressurization are discussed in comparison with ship motions and accelerations.

EXPRIMENTAL APPARATUS AND METHOD

Figure 1 shows a measurement system. This system consists of an optical cryostat (a small LH_2 tank), five MgB_2 level sensors, two CCS temperature sensors, a digital pressure sensor, current sources for the level sensors and the CCS sensors, a power supply for the external heater of level sensor, a data logger (KEYENCE; NR-600), a GPS-aided mems inertial system (MEMSIC; NAV440) and a PC. The optical cryostat having a height of 1327 mm is composed of a vacuum jacket, an LH_2 space (20 L), an LN_2 space (15 L), a 77 K aluminum shield, and five optical windows having an effective diameter of 60 mm. The layout of five 500-mm-long MgB_2 level sensors of A1, A2, B1, B2, and C is shown in Figure 1. The CCS sensors A and B were attached on the level sensor support with distance of 250 mm and 125 mm from the bottom of the level sensor, respectively. The data of liquid level, temperature, and pressure inside the cryostat was obtained by NR-600, and the data of ship motions with accelerations of X, Y, and Z direction was obtained by NAV440 through a shipboard LAN. All data was synchronously collected by a PC with the GPS clock. Figure 2 shows a photograph of the experimental setup on afterdeck of the training ship "Fukae-maru", which has 50 m long and 449 ton gross weight. All electronic equipment was placed in another room on board to make them explosion-proof.

Table 1 shows a time chart of experimental processes inside Osaka bay on February 2, 2017, and also Figure 3 shows a track chart of "Fukae-maru" inside Osaka bay. In the table, test numbers ①-⑥ refer to experimental processes in the transportation test by ship; ①-③ denote rapid depressurizations with a release valve, ④ denotes drifting after stopping engine under the influence of natural wind and wave, ⑤ denotes zig-zag maneuver test after sharp turning maneuver, ⑥ denotes sharp turn at 360-dgree circle as shown in Figure 3. The liquid level detected by five 500-mm-long MgB_2 level sensors at a heater input of 9 W, temperature, and pressure inside the cryostat were measured synchronously during ①-⑤. On the other hand, temperature and pressure without the liquid level at a heater input of zero were measured synchronously during ⑥.

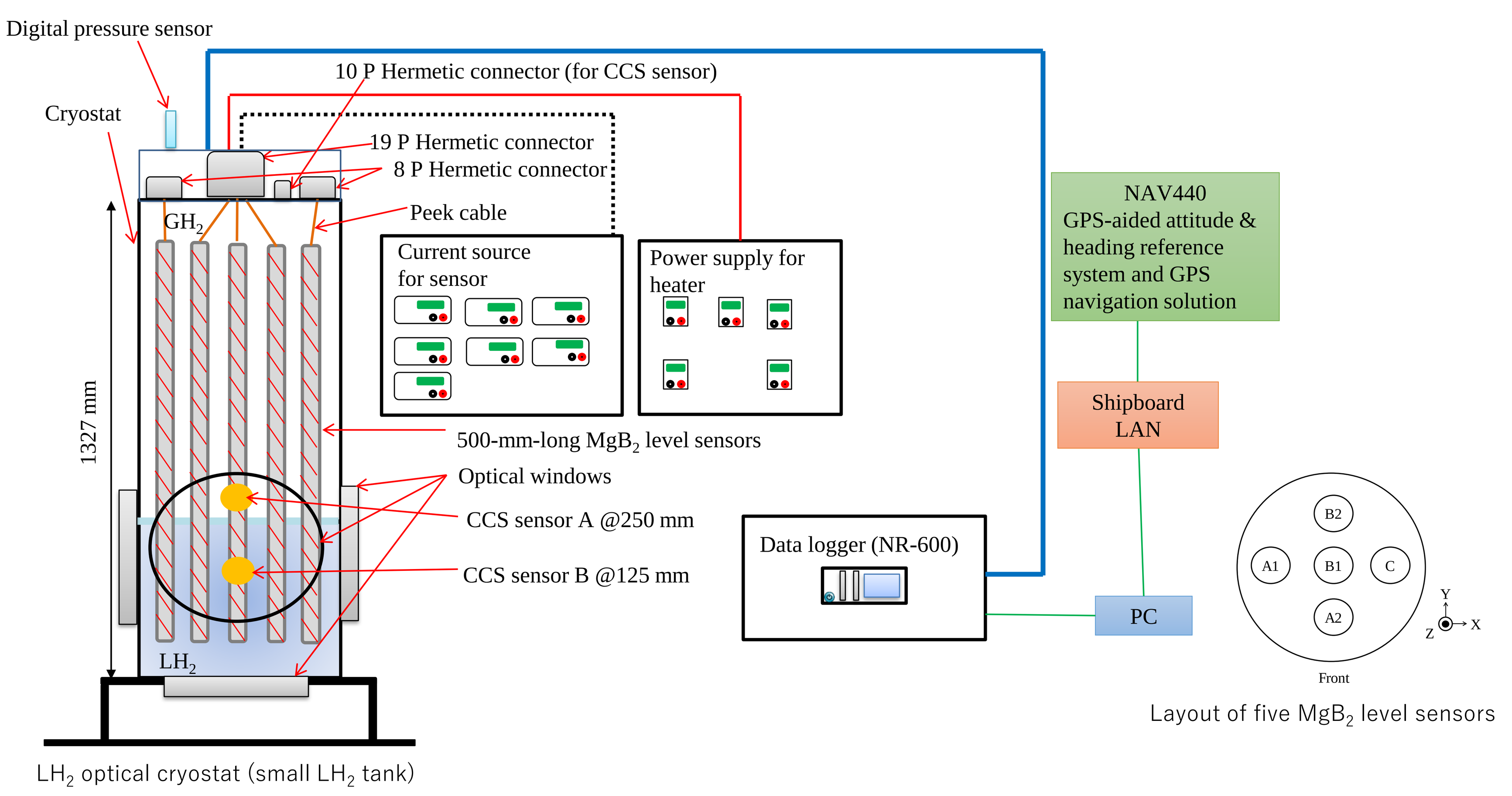

Figure 1. Measurement system.

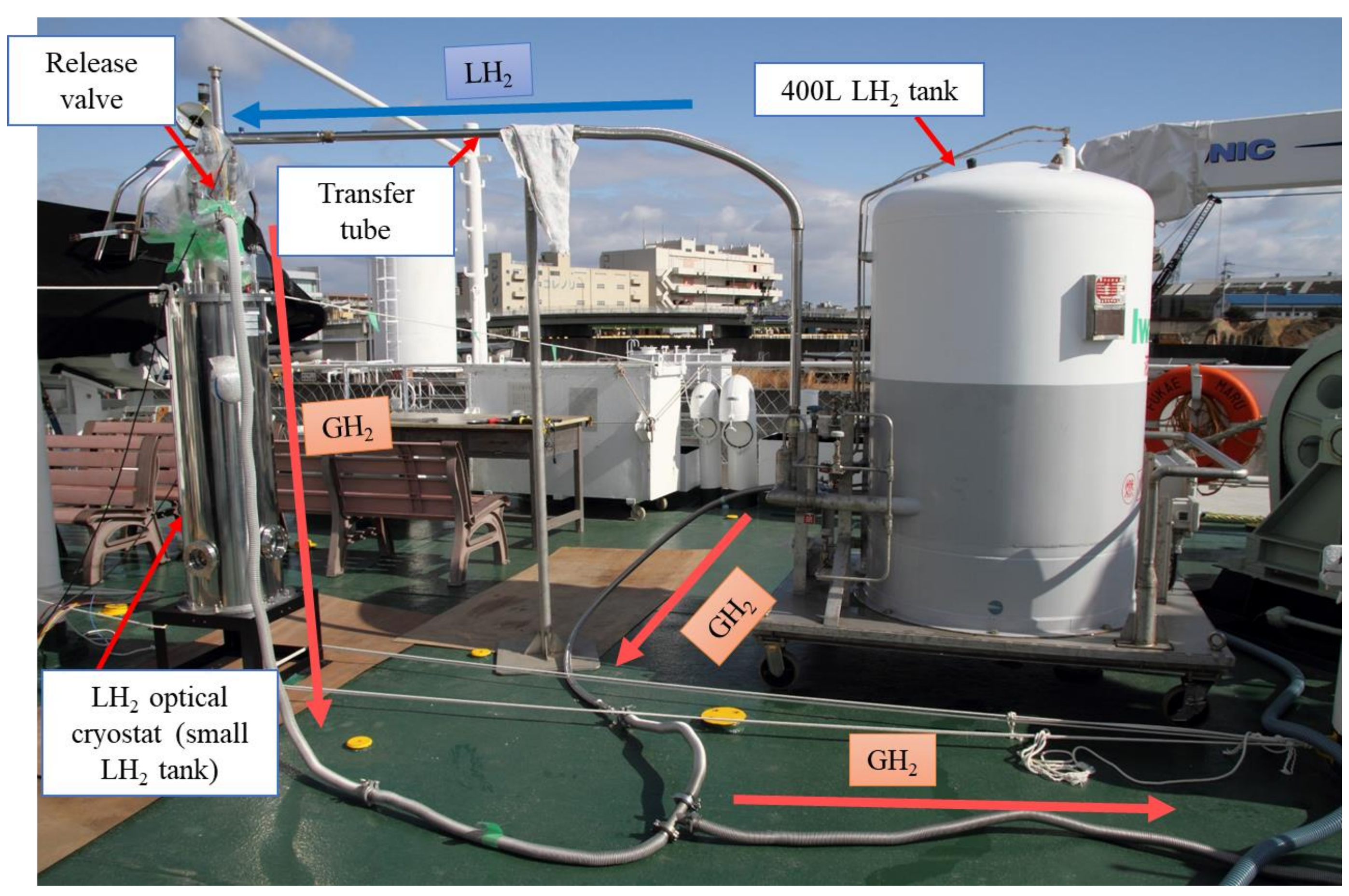

Figure 2. Photograph of experimental setup on afterdeck.

Table 1. Time chart of experimental processes inside Osaka bay.

Time	Process	Test number
12:53	Leave port	①
13:02	Release valve close	
13:22	Release valve open (rapid depressurization)	
13:25	Release valve close	②
13.42	Release valve open (rapid depressurization)	
13:45	Release valve close	③
14:02	Release valve open (rapid depressurization)	
14:10	Release valve close	④
14:10	Start drifting after stopping engine	
14:17	Finish, Release valve open (rapid depressurization)	
14:30	Release valve close, A sharp turning maneuver	⑤
14:35	Zig-zag maneuvrer test	
14:42	Finish	
14:45	A sharp turn at 360-degree circle	⑥
14:49	A ninety degrees sharp turn to the left	
14:51	Finish	
14:55	A sharp turn at 360-degree circle	
14:58	Finish	
15:58	A sharp turn at 360-degree circle	
16:17	Enter port	

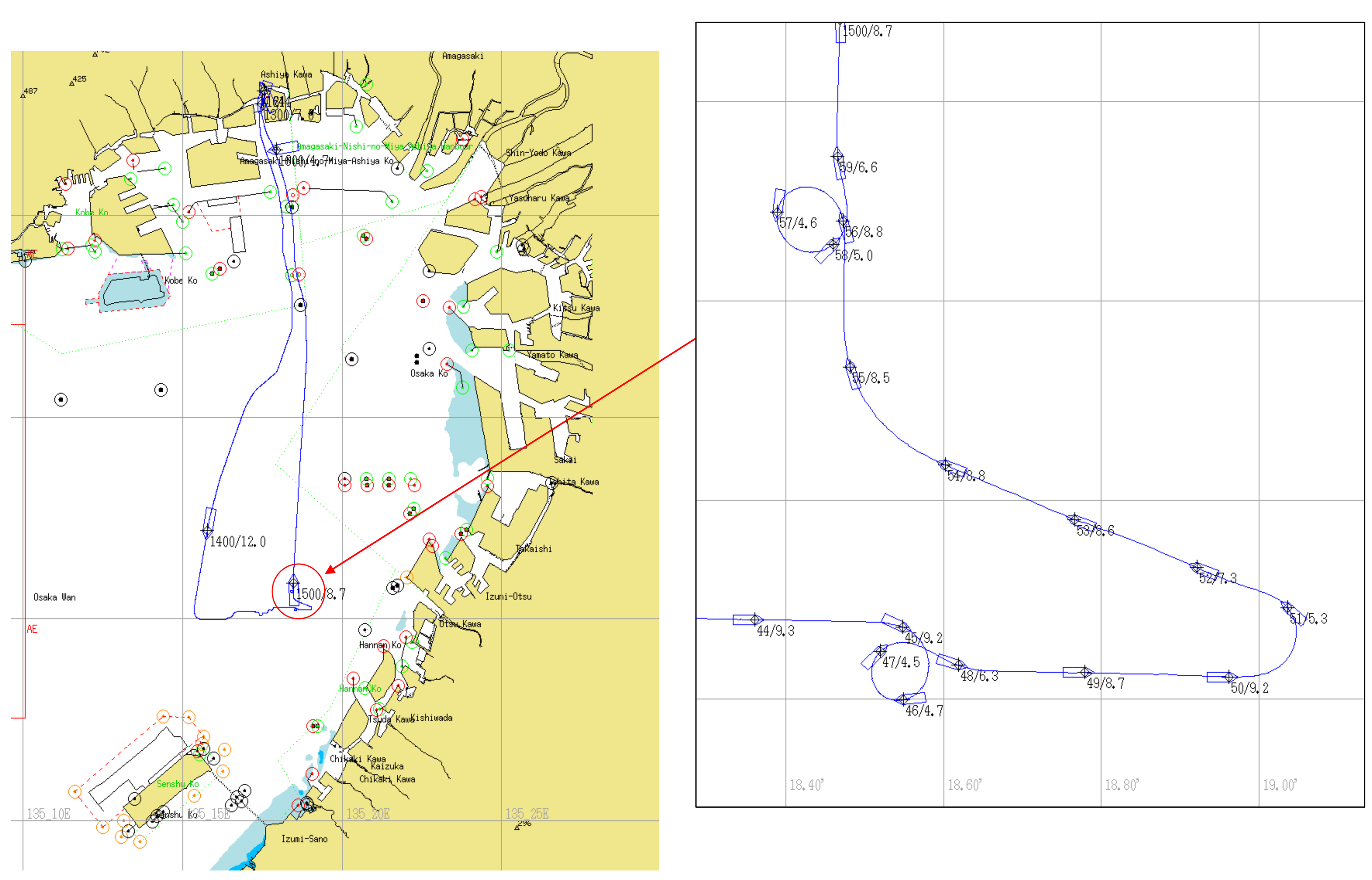

Figure 3. Track chart of "Fukae-maru" inside Osaka bay.

EXPERIMENTAL RESULTS

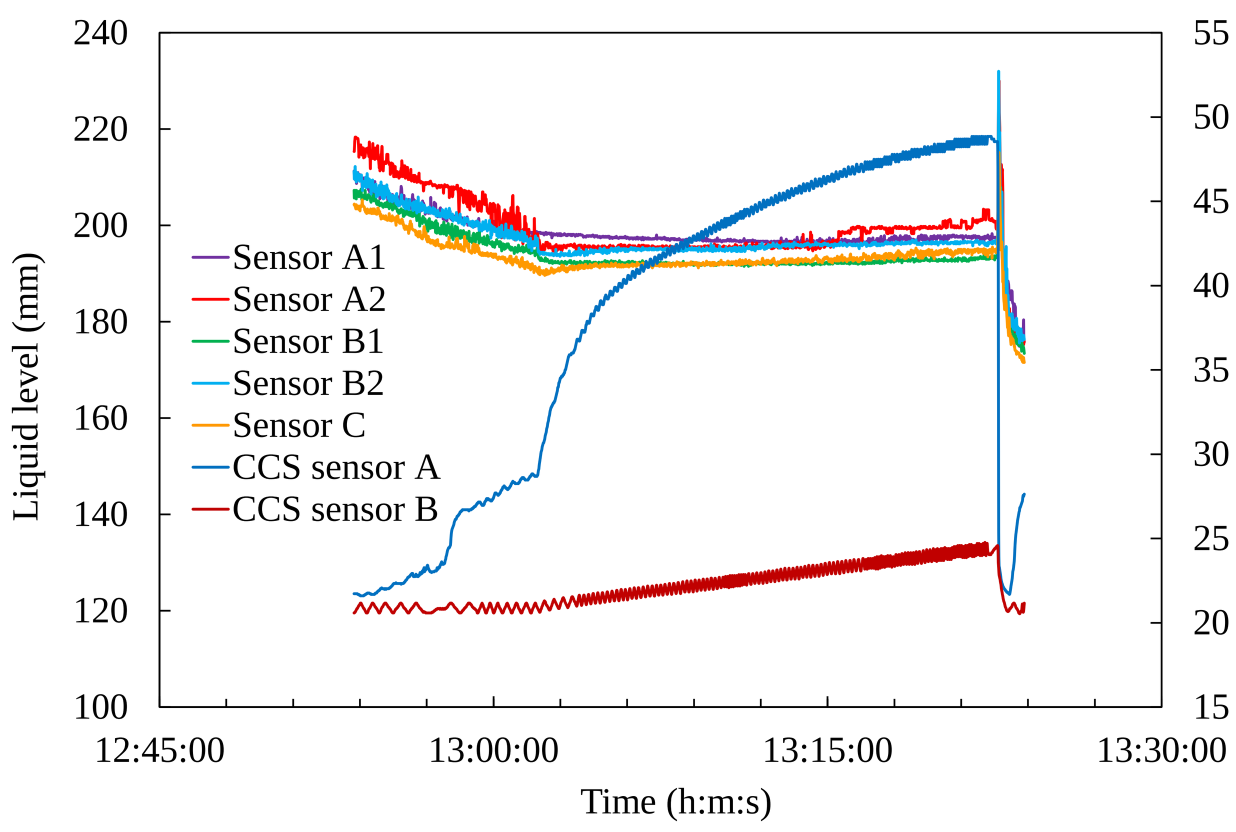

Figure 4. Time chart of liquid level and pressure inside the cryostat during marine transportation test ① from 12:53pm to 1:22pm.

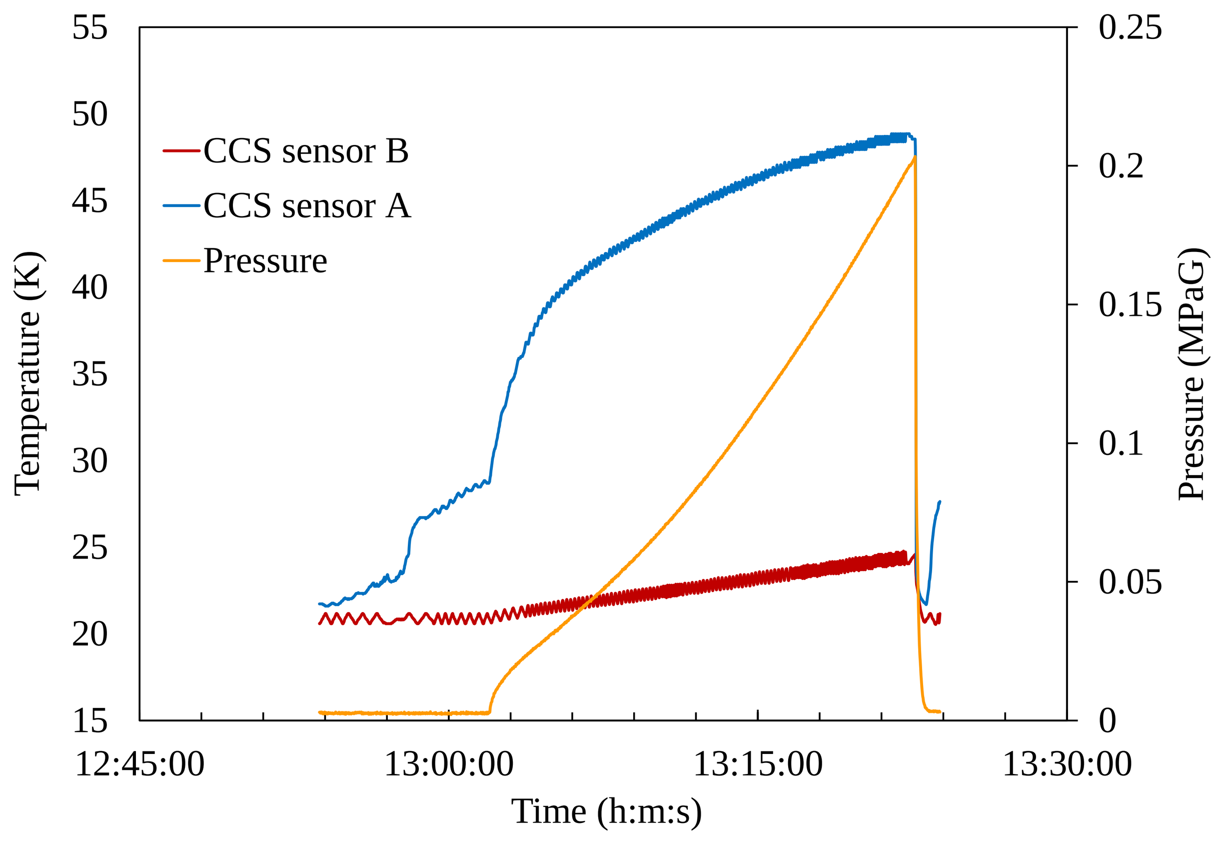

Figure 5. Time chart of temperature and pressure inside the cryostat during marine transportation test ① from 12:53pm to 1:22pm.

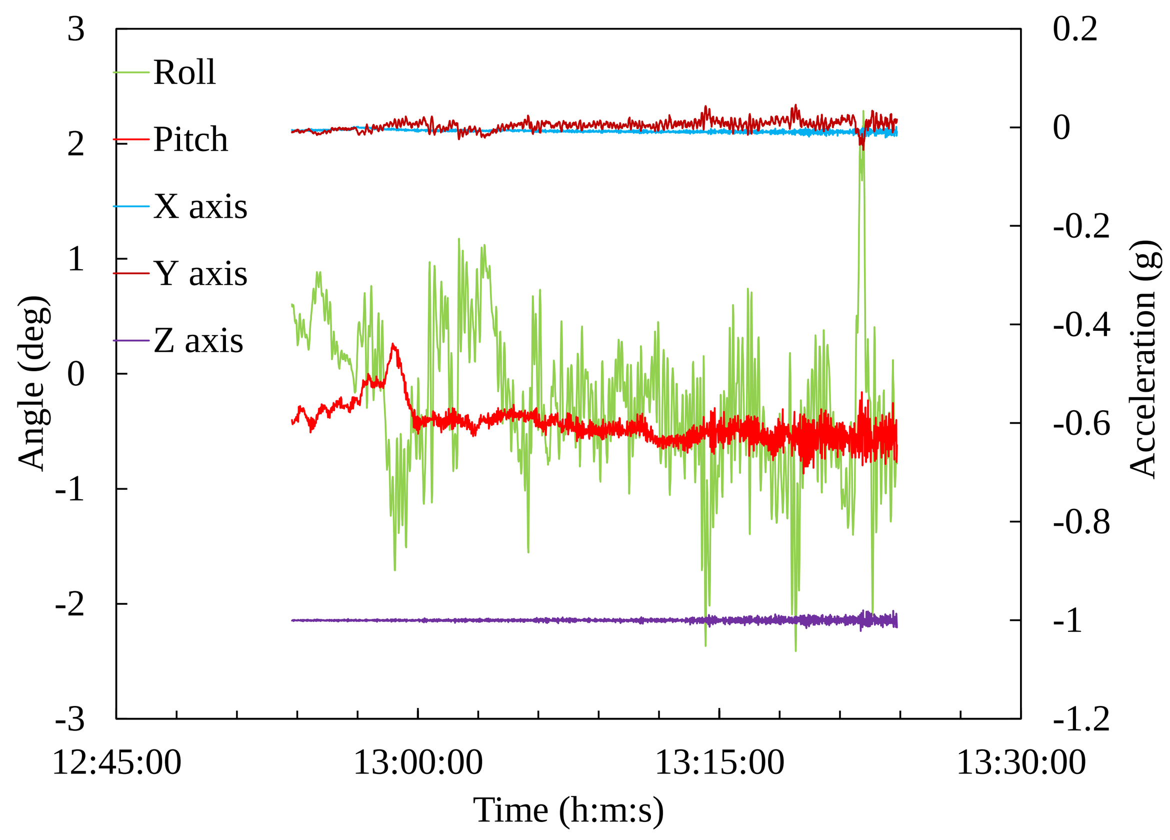

Figure 6. Time chart of angle and acceleration during marine transportation test ① from 12:53pm to 1:22pm.

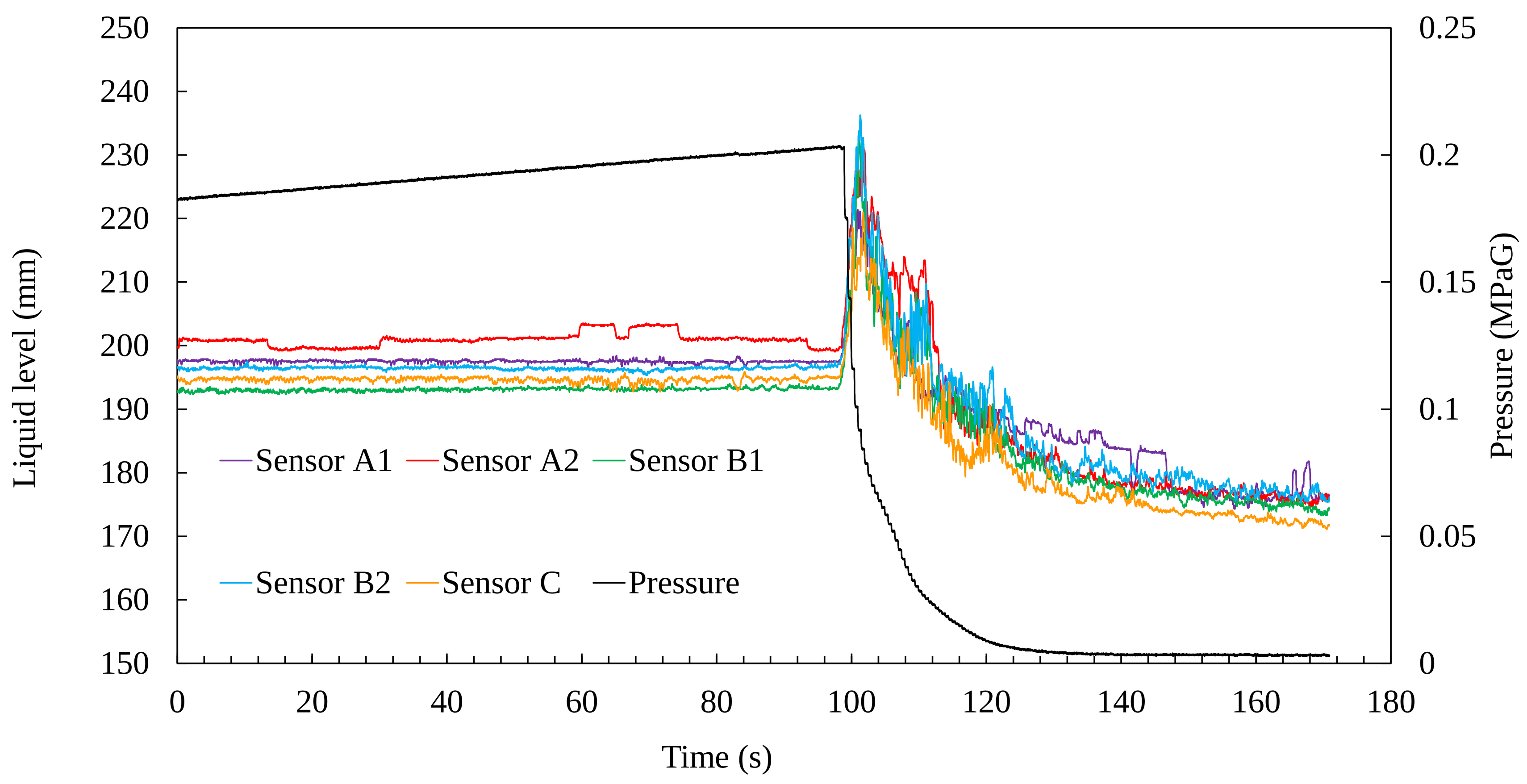

Figure 7. Time chart of liquid level and pressure inside the cryostat under rapid depressurization.

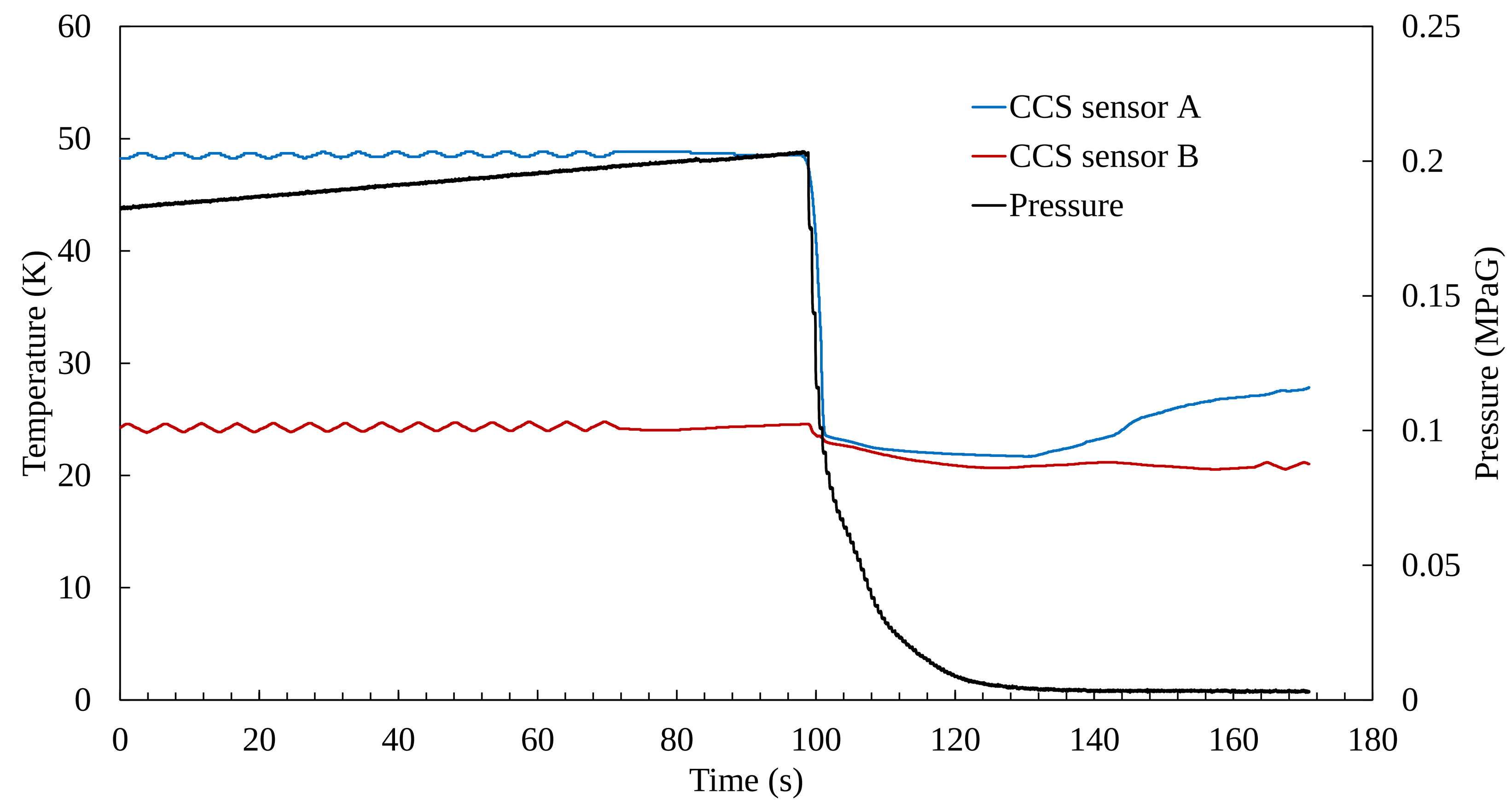

Figure 8. Time chart of temperature and pressure inside the cryostat under rapid depressurization.

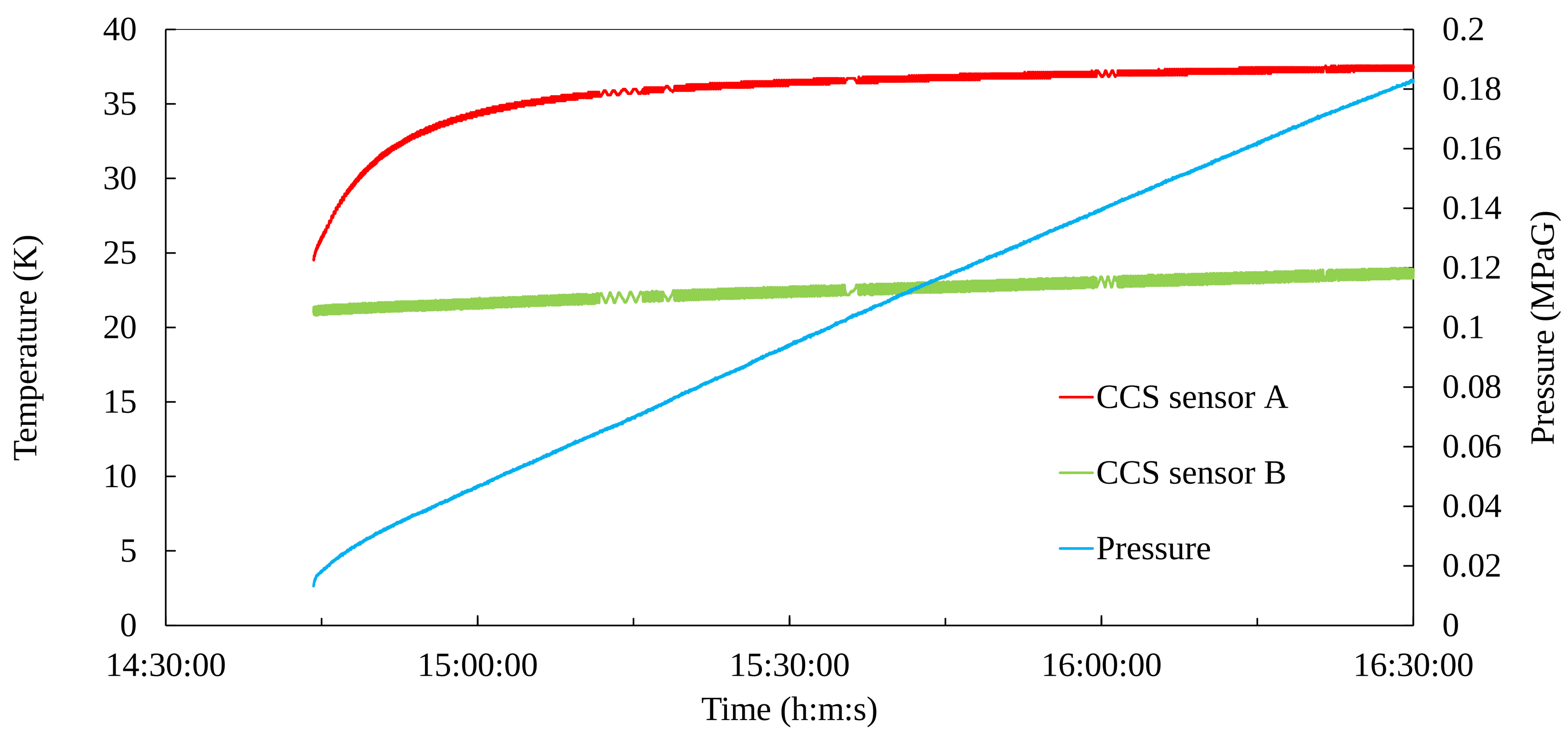

Figure 9. Time chart of temperature and pressure inside the cryostat during marine transportation test ⑥ from 2:45pm to 4:30pm.

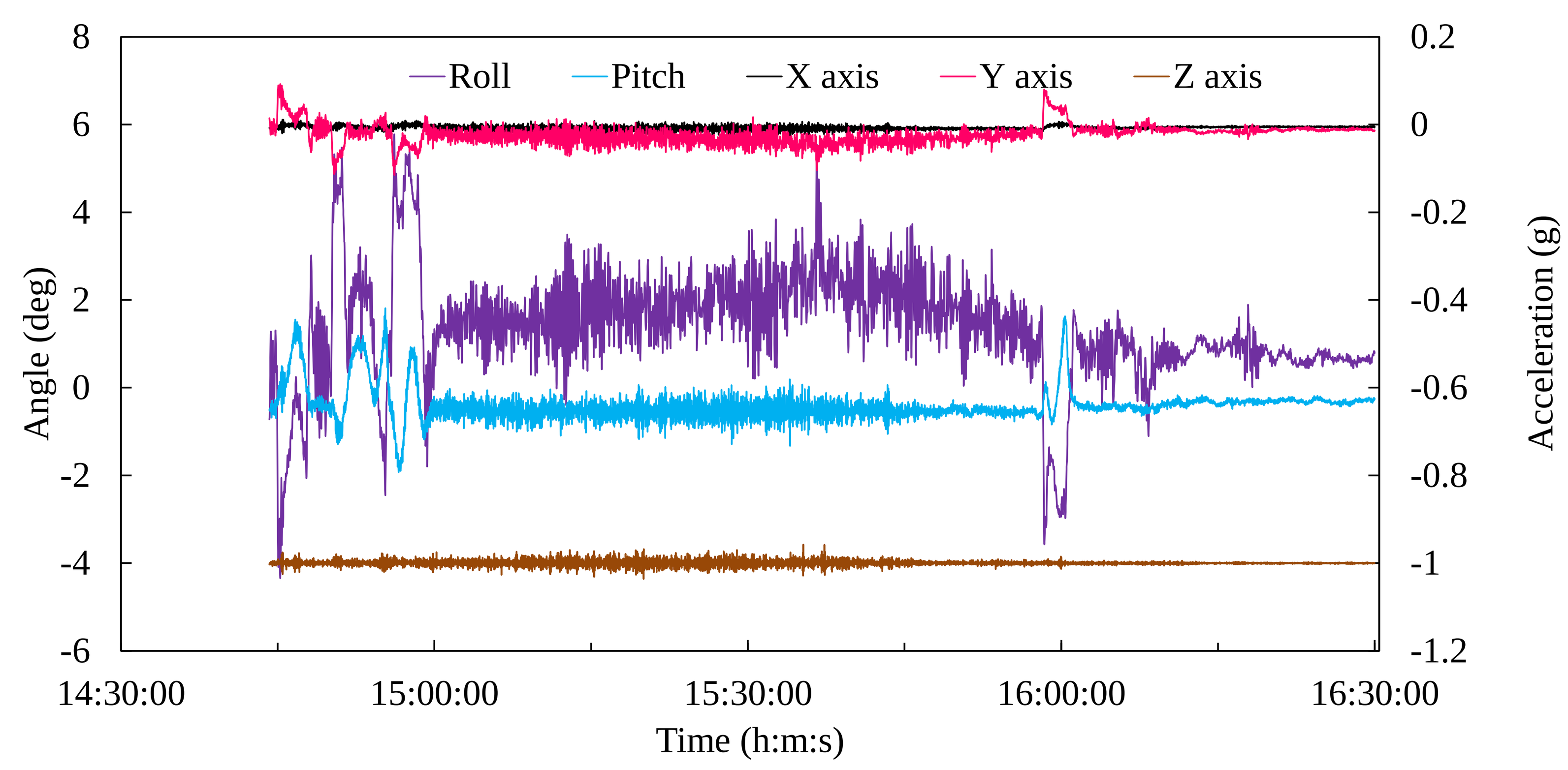

Figure 10. Time chart of angle and acceleration inside the cryostat during marine transportation test ⑥ from 2:45pm to 4:30pm.

Experimental results of test numbers ① and ⑥ were paid main attention for data analysis. Figures 4-6 show experimental results of liquid level, temperature, pressure, ship motions, and acceleration during ①, using every 1 s data. As shown in Figure 4, the temperature of CCS sensor A upward the liquid level increased from 12:57pm to 12:58pm. At the same time, rolling of the ship motions occurred as seem in Figure 6. This is thought to be caused by temperature increase of gaseous phase due to heat exchange between inner wall and hydrogen gas after sloshing inside the cryostat. As shown in Figure 5, the temperature of CCS sensor B downward the liquid level increased with increasing the pressure inside the cryostat after closing the release valve at 1:02pm. This is believed to be caused by an increase of saturated temperature of liquid phase due to an increase of the pressure.

Rapid depressurization tests were done with opening the release valve after achieving the pressure of 0.2 MPaG at 1:22pm. Figures 7 and 8 show the details during 170 s after 1:21pm, using every 0.01 s data. As seen in Figure 7, maximun increase of 30 mm liquid level with heavy sloshing was observed, just after rapid depressurization. In addition, the average liquid level decreased with decreasing the pressure under rapid depressurization. As seen in Figure 8, it was found that the temperature of CCS sensor A decreased rapidly and the temperature of CSS sensor B decreased gradually, just after rapid depressurization. In addition, the temperature of CCS sensor A increased gradually under the low stable pressure.

The details of test number ⑥ without the liquid level measurement is shown in Figures 9 and 10. Aa shown in Figure 9, the temperature of CCS sensor A increased immediately just after a sharp turn at 360-degree circle. This is thought to be caused by heavy sloshing inside the cryostat due to a sharp turn. At the same time, the ship rolled greatly with a maximum rolling angle of six degree and a maximum acceleration of 0.1 g, where g is gravitational acceleration.

SUMMARY

First experiment on the LH_2 transportation of 20 liter including rapid depressurization tests with five 500-mm-long MgB_2 level sensors by the training ship "Fukae-maru" was carried out successfully inside Osaka bay on February 2, 2017. Experimental results of liquid level, temperature, and pressure inside the cryostat were closely related to the ship motions and the accelerations.

Acknowledgements

The authors would like to thank Professor Captain Yoshiji Yano and Professor Nobukazu Wakabayashi for helpful discussions and technical support. This work was supported in part by a Grant-in Aid for Scientific Research, JSPS KAKENHI Grant Number 24246143, Japan.