Model Experiments in Following and Quartering Seas using a Small Size Ship Model

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Abstract: In case of performing a free-running model test, a large scale of ship model and basin are conventionally required because of the need of installing a lot of driving and measuring apparatus. They generally need the large cost for the model test. Therefore, it would be better and convenient if a small free-running ship model could be realized.

The authors have been trying to develop the small size of driving and measuring apparatus for such a small size ship model, and trying to carry out free-running model tests in waves at a small basin. Although there are significant problems about weight and space for the onboard apparatus, the small size of servo driving unit of propulsion motor as well as steering gear have been developed. The electric power for these apparatus is supplied by only one small lithium-polymer battery. Meanwhile, for the measurement of ship trajectory and speed, a total station system is utilized.

Using such ship model, the authors have successfully measured the ship motion of surf-riding and broaching, and reveal the occurrence condition of these phenomena as an example. From these data, initial conditions of surf-riding and broaching also can be clarified even in such small ship model and towing basin.

Key words: small size ship model, free-running model test in waves, surf-riding, broaching.

1. Introduction

Free-running model tests are essential and important for the study of maneuvering and sea-keeping performances. When these tests are performed, a lot of driving and measuring apparatus must be installed on a ship model. They are, for example, radio control receiver, battery, propulsion motor, steering gear; motion sensor, data logger and so on. Therefore, a large scale of ship model should be arranged, which requires a large model basin and also introduces a large cost for model testing.

In particular performing a free-running test in waves, the sufficient water proof device should be provided against the deck water caused by waves and sometimes the capsizing of ship model. This makes the ship model heavier, which introduces the larger cost for model tests.

In this paper, some method of free-running test using the small size ship model is proposed. Then, the results of model tests are shown, particularly in the following and quartering waves.

2. Method of free-running model test

Firstly, the methods of free-running model tests using a small ship model are shown. In order to install all the apparatus into the small model, smaller and lighter instruments have been developed. At the same time, the hull structure of ship model also has become lighter construction using some frames and FRP hull. As for the measurement of ship trajectory and speed, a total station system is applied.

2.1 Ship model

In this paper, 135GT purse seiner is investigated. The photograph of the ship model is shown in Fig.1. This kind of purse seiner is one of the typical fishing vessels in Japan and some of them caused the capsize accidents.

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Fig. 1 – Ship model for free-running tests

Table 1 Principal particulars of the ship mode

		full-scale		model	
scale				1/35	
L_{pp}	m	37.00		1.057	
B	m	7.90		0.226	
D	m	3.22		0.092	
d	m	2.90		0.083	
DISP.		483.60	(t)	11.056	(kg)
KM	m	4.56		0.130	
KG	m	3.09		0.096	
GM	m	1.47		0.034	

The principal particular is shown in Table 1. It may be remarkable that the ship model length and the displacement are only 1.1m and 11kg, respectively.

2.2 Driving apparatus

1. Battery

Conventionally, lead batteries or nickel-cadmium batteries were used as a power supply of a ship model. However, these batteries are too heavy to install into a small ship model. Therefore, a lithium-polymer battery that is called a Li-Po battery is applied to the power source of the small ship model. This kind of battery is now widely used in the hobby airplane or helicopter. The size of 6 cell type battery as shown in Fig.2 is only 150mm×50mm×50mm, and the weight is less than 800g. The electric power is 22.2V and 5,800mAh at full charge.

This small but powerful battery can realize the experiment by means of supplying the electric power for all apparatus on board. The important points for using this battery are concerning to the electric charging and discharging. A computer controlled charger as shown in Fig.2 should be used for the battery charging. While the operation of model tests, the voltage of the battery should be carefully monitored and checked in order not to make over discharging condition that may break the battery.

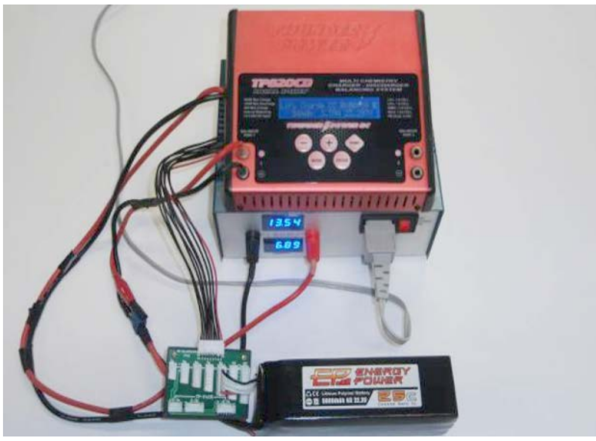


Fig. 2 – Lithium-polymer battery and its charger

Fig. 3 – Propulsion motor (60W DC motor)

2. Propulsion motor

In order to reduce the weight and space of a propulsion motor, a small size DC motor shown in Fig.3 has been used. The maximum power is 60W and the weight is only 0.7kg.

For the connection between propeller shaft and motor shaft, one helical coupling has been used as shown in Fig.4. This coupling can absorb the vibration caused by the small off center among these shafts.

3. Steering gear

As for the steering gear, the conventional servo motor of a proportional radio controller has been connected to the rudder pintle using one set of link lever. Rudder angle is detected by a small potentiometer which is connected by another link levers from the rudder pintle. These mechanisms are shown in Fig. 5.

4. Propulsion motor controller

The revolution of the propulsion motor is precisely kept constant during the model test. For this purpose, PDI controlled power driver including ahead/astern controller has been specially manufactured and mounted in a compact box as shown in Fig.6.

2.3 Measuring devices on board

Measuring devices on board and data recorder have been selected and used from the market.

1. 6DOF inertial sensor

In order to measure the ship motions, a 6DOF inertial sensor (Crossbow AHR5400MA) shown in Fig.7 has been used. It is able to measure the accelerations in 3 directions and roll, pitch, yaw angle and rate. The size is 75mm×75mm×100mm and weight is 720g.

2. Data recorder

As there is little space to install PC on board, a small size data logger (Keyence NR-2000) has been used. The size is 165mm×110mm×30mm. It can simultaneously record 16 measuring channels. This recorder has been stored in a watertight plastic box for food and fixed on the deck to operate it easily.

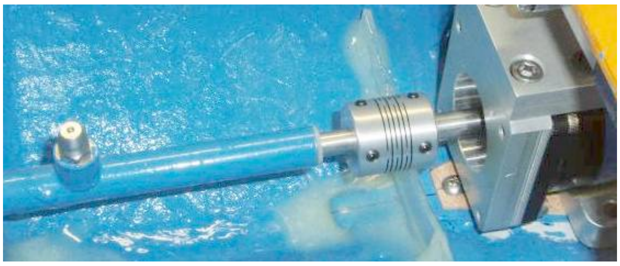


Fig. 4 – Connection of motor and propeller shafts

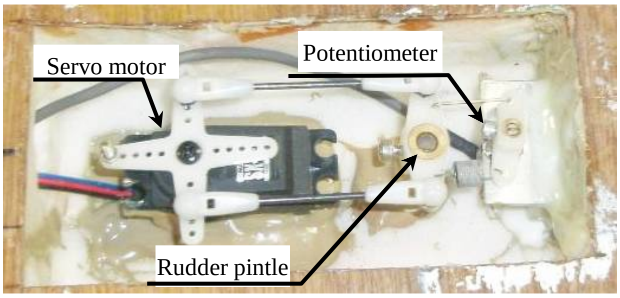


Fig.5 – Steering gear

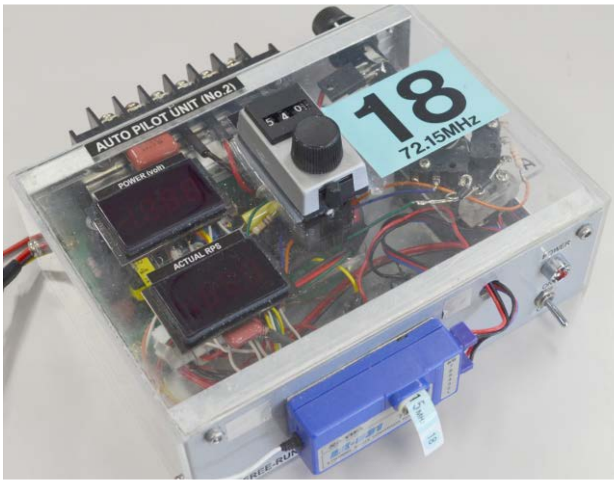


Fig. 6 –Compact control box

Fig. 7 –Data logger and 6DOF inertial sensor

2.4 Measurement of ship trajectory and speed

Although ship motions can be measure from the 6DOF inertial sensor, the ship trajectory and speed can not be obtained from the onboard data. The ship trajectory and speed should be measured from the shore. In this paper, a total station system shown in Fig.8 (Topcon / Power Station) is utilized. It is now widely used in civil engineers. This device can automatically track the laser lay reflected by the prism which is located on the top center of ship model, and calculate in 20Hz the 3D position of the prism that is the center of ship model.

Using the above 3D position data, ship's speed can be obtained by means of time differentiating these data. However, there are some small noises and errors in these 3D position data, this makes the large scatters in the calculated speed data. One example is shown in the pink line of Fig. 9. Therefore, some filtering technique should be applied.

In this paper, a simple differential digital filter has been used to eliminate the noise. The algorism of this filter is explained as in (1).

$$\left.\begin{aligned} u(k\Delta t) &= \Delta t \sum_{i=-N}^{N} x((k-i)\Delta t) W(i\Delta t) \\ v(k\Delta t) &= \Delta t \sum_{i=-N}^{N} y((k-i)\Delta t) W(i\Delta t) \\ U(k\Delta t) &= \sqrt{u^2(k\Delta t) + v^2(k\Delta t)} \end{aligned}\right\} \quad (1)$$

Where, $x(t)$, $y(t)$: measured position data

$u(t)$, $v(t)$: calculated speed

$U(t)$: resultant ship's speed

$W(t)$: impulse response of differential and low-pass filter with window function

Δt: sampling interval of data

This simple digital filter can realize an arbitral frequency response if necessary.

The obtained ship's speed using the above differential low-pass filter (cutoff frequency: 1Hz) is shown in straight bold line in Fig.10. It is found that the scatters can be well eliminated instead of phase-lag.

Fig. 8 – Total station system

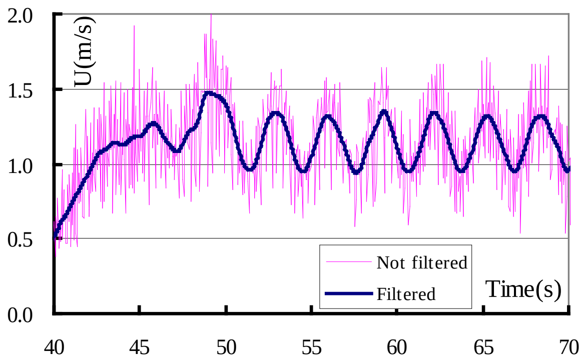


Fig. 9 – Comparison of a ship's speed between simple differentiation and digital filtering

3. Model experiments in following and quartering seas

Model tests have been performed concerning to reveal the occurrence condition of surf-riding and broaching. A small towing basin in Hokkaido University whose size is 50m×3.5m×1.5m has been used. Model tests have been carried out in following and quartering seas. The ship model is accelerated to a certain speed by a towing carriage, and then it is released from the carriage. After that, it is course-kept by a manual steering. According to the Ref. [1], surf-riding is divided into under any initial condition and under certain initial condition. Therefore, the experiments in this paper become the surf-riding under certain condition. F_n and χ_c are adopted as the test parameters. F_n means a nominal Froude number that indicates non-dimensional ship speed in calm water with the specified propeller rps, and χ_c course keeping angle from wave direction, respectively.

3.1 Patterns of test results

Test results are classified to 4 patterns that are periodic motion, surf-riding, nearly broaching and broaching.

In case of a ship running high speed in following seas, the ship is sometimes caught by waves and accelerated to the same speed of wave celerity. It is called as surf-riding. During this surf-riding, the ship tends to fall into the severe condition that she can not maintain her course and until at last she quickly turns. It is known as broaching that often causes a capsizing. Therefore, surf-riding has to be considered as a necessary condition of broaching.

In order to categorize these 4 patterns, ship's motion are determined using the coordinate systems as shown in Fig.10. Typical examples of each time series are also shown in Fig.11.

1. Periodic motion

When a ship is running in following seas, the ship is generally overtaken by waves. Pitching angle is varying periodically. Therefore it is defined as periodic motion and expressed as in (2).

$$\theta \neq const. \qquad (2)$$

2. Surf-riding

In case of surf-riding, pitching angle becomes to be not periodic and substantially constant in negative angle, since the ship almost locates a down slope of the same wave successively. It is defined as surf-riding and expressed as in (3)

$$\theta \approx const. < 0 \qquad (3)$$

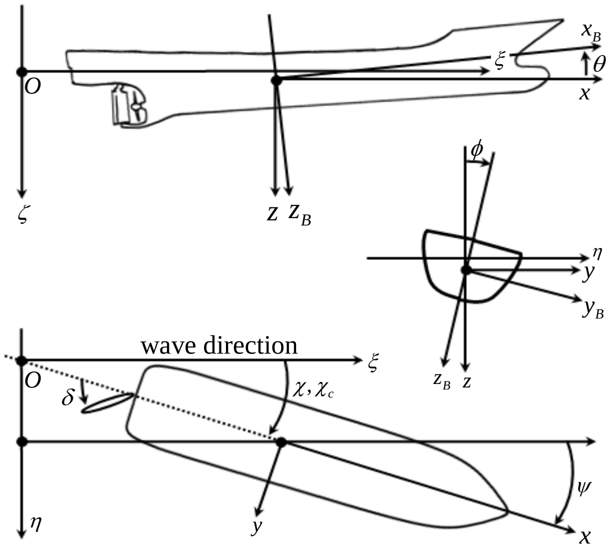


Fig. 10 – Coordinate systems

3. Nearly broaching

In spite of the maximum steering effort, the ship does not promptly respond; it is regarded as nearly broaching and expressed as in (4). The previously mentioned surf-riding condition is also added in this pattern.

$$\begin{aligned} &\theta \approx const. < 0 \\ &\delta = +\delta_{\max}, r = 0 \quad or \quad \delta = -\delta_{\max}, r = 0 \end{aligned} \qquad (4)$$

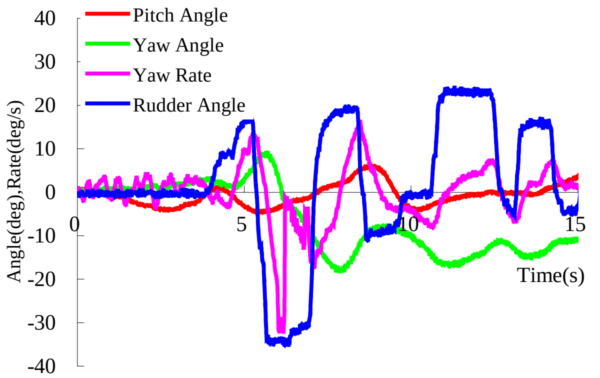
where, δ_{max}=35 is maximum rudder angle

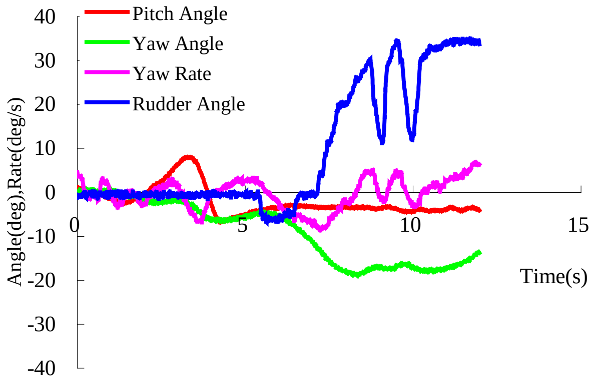
This pattern may reach to broaching. Particularly, the results of experiment in a small basin sometimes can not determine whether the ship will turn to the steering side or not, since the ship model has been running just a limited distance. This pattern is including such result.

4. *Broaching*

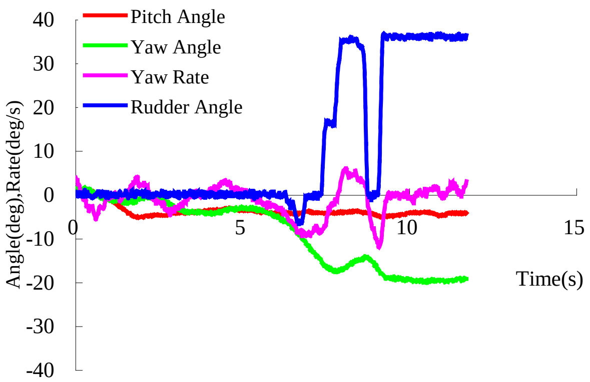
In case of the ship turning to the opposite direction against to the steering side in spite of the maximum steering effort, it is defined to be broaching. Broaching is defined as in (5) according to Ref. [2].

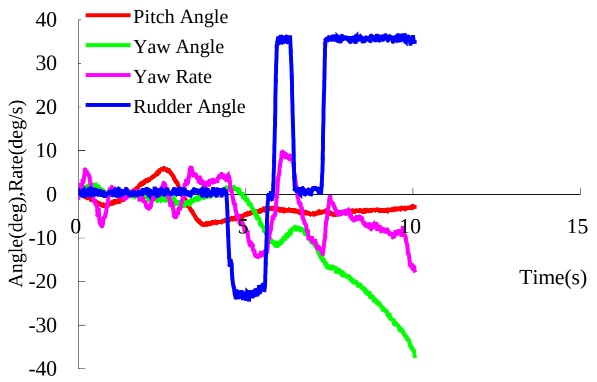
$$\begin{aligned} &\delta = +\delta_{\max}, r < 0, \dot{r} < 0 \quad or \\ &\delta = -\delta_{\max}, r > 0, \dot{r} < 0 \end{aligned} \qquad (5)$$





(a) Time series of periodic motion with H/λ=1/20 (b) Time series of surf-riding with H/λ=1/16





(c): Time series of nearly broaching with H/λ=1/15.5 (d) Time series of broaching with H/λ=1/15

Fig.11 – An example of each definition (Every examples are carried out with λ/L=2.1, χ_c=-10degrees and F_n=0.43.)

3.2 Occurrence condition of broaching

Experiments have been carried out in quartering seas. The wave condition is λ/L=2.1 and H/λ=1/19, 1/17 and 1/15.5. The ship model has been course-kept to χ_c=-5, -10 and -15 degrees; propeller rps has been set to be F_n=0.35, 0.40 and 0.43.

Results of the experiments are categorized to the previous mentioned patterns and the probability of broaching are obtained and plotted in Fig.12 for various test parameters. From this figure, it is clear that the probability of broaching is increased by the larger F_n, H/λ and χ_c.

However, as χ_c is limited to -15 degrees in this experiment and the probability can not be obtained over this angle. According to Ref.[3], it is expected that the ship model is overtaken by waves when χ_c is over -15 degrees, and then the occurrence of broaching may reduce.

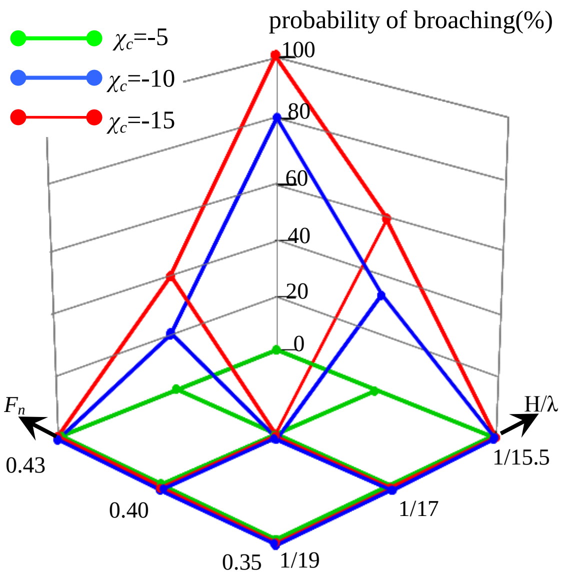
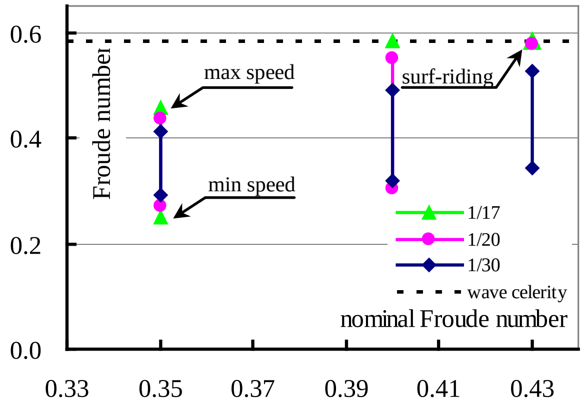


Fig. 12 – Occurrence condition of broaching

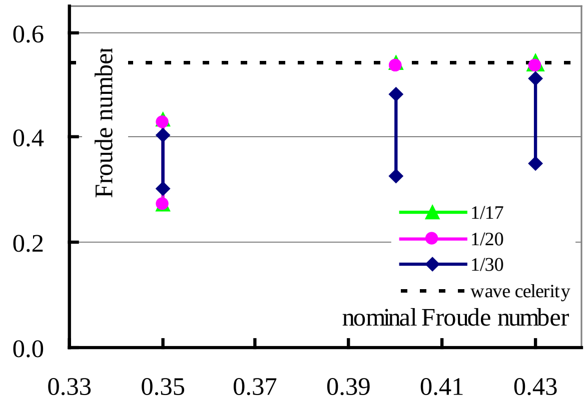
From the above results, it can be pointed out that the reduction of ship's speed or course-keeping direction to the wave is important in following seas.

3.2 ship speed in following seas

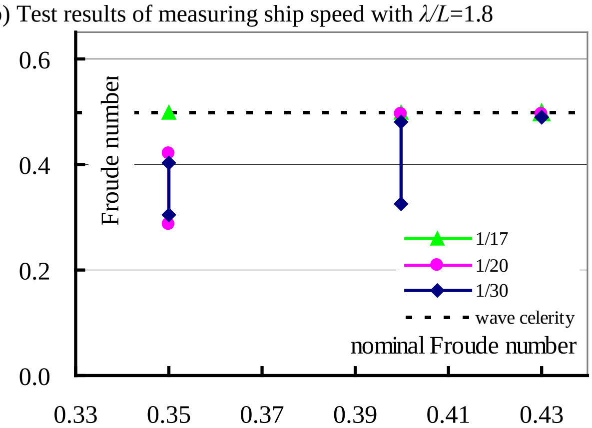
At the previously mentioned experiments, ship's speed is also measured. Fig.13 shows the measured ship's speed in following seas where χ_c=0 and various λ/L, H/λ and F_n. The horizontal axis indicates nominal Froude number that is corresponding to the propeller rps, and the vertical axis is actual ship speed converting to Froude number. Each figures show that the actual ship's speed becomes higher when propeller rps or H/λ increasing. Also, two different patterns can be seen. One is the case that the ship model has been overtaken by waves and then ship's speed changes periodically. The other is that the ship's speed has been accelerated and reached to the wave celerity that is shown by the dotted line in each figure. This is surf-riding condition. In case of approaching to the surf-riding condition, amplitude of ship's speed becomes larger. This tendency is known as a surging with large amplitude in Ref. [4]. It is considered to be the signal of a surf-riding.



(a) Test results of measuring ship speed with λ/L=2.1



(b) Test results of measuring ship speed with λ/L=1.8



(c) Test results of measuring ship speed with λ/L=1.5

Fig. 13 – ship seed in following seas

4. For the future study

In order to perform model test more precisely, smaller size devices have been developed. These devices are shown in Fig.14. The total weight of altered devices is just 6kg. In order to adjust the ship's trim and moment of inertia easily, a little bit larger ship model is constructed. The length and displacement are about 1.2m and 14kg.

1. Auto-pilot device

In order to keep ship's course exactly and automatically, an intelligent auto-pilot unit is added in the compact control box. It is shown in Fig.14 (a). It is expected that the uncertainty at course keeping maneuver can be decreased by using this unit.

2. Compact size propulsion dynamometer

A conventional propulsion dynamometer in the market is too large and heavy for such a small ship model to measure the propeller thrust and torque.

For this purpose, a compact size propulsion dynamometer is developed. It is shown in Fig.14 (b). The previous mentioned compact propulsion motor is suspended by a dynamometer by which the propeller thrust can be directly measured. As for the propeller torque, the electric current of the propulsion motor is precisely converted to the torque. These electric circuits are additionally installed in the above auto-pilot unit.

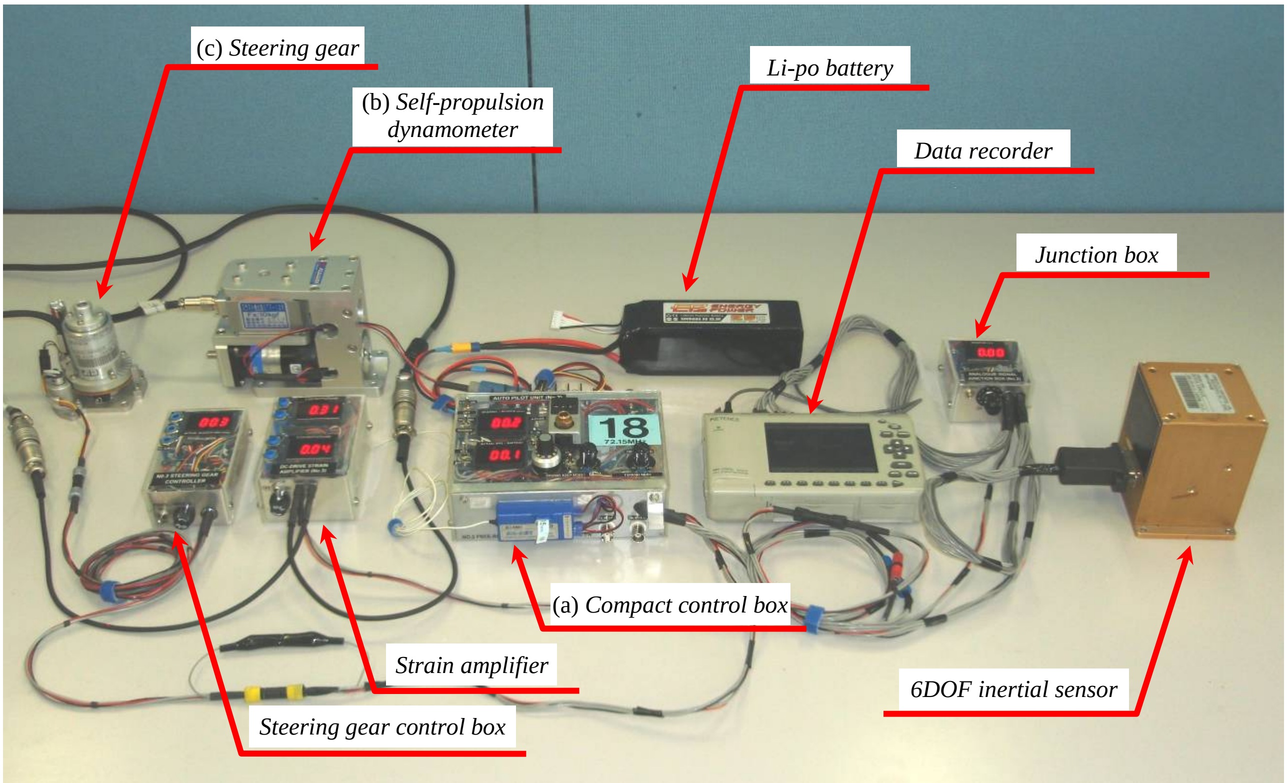


Fig.14 – Driving and measure devices for the future experiments

3. Small size steering gear

A servo controlled steering is essential for the auto-pilot steering. For this purpose, a small size of steering gear has been developed. It is shown in Fig.14 (c). Moreover, an accurate load cell can be attached on this steering gear, which can measure rudder normal force precisely.

5. Conclusions

The experimental technique using the small ship model is proposed here. Model tests have been carried out in the small towing basin. The concluding remarks are summarized as the following.

1. Utilizing a small size of ship model, ship motions during free-running in following and quartering seas can be obtained even in a small towing basin. As for broaching, however, only initial conditions have been clarified.
2. Although there are some uncertainties in the course keeping because of the manual steering, the outlines of broaching occurrence conditions can be clarified.
3. Ship speed and trajectory can be successfully measured using a total station system, and also the surging with large amplitude in waves can be measured.

As the results, a small ship model is considered to be an effective method. However, in case of the investigation of the capsizing due to broaching, a larger basin may be essential.

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