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Design and construction of 6-component balance dynamometer for measurement of the forces, moments andmotions of ship models in the towing tank

[1]*M. Atashrazm Jirande;* [1*]*F. Azarsina;* [2]*M. S. Seif*

[1] *Department of Naval Architecture, Science and Research Branch, Islamic Azad University, Tehran, Iran*
[2] *Department of Mechanical Engineering, Sharif University of Technology, Tehran, Iran*

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ABSTRACT: During design spiral of a merchant ship or a naval vessel, it is important to perform towing tank tests in order to measure its performance either in calm water maneuvers or in waves for seakeeping performance. Also, to optimize a hydrodynamic design, towing tank tests are advantageous.This article presents the results of an applied research project. The objective of this project is to design and manufacture a six-componentbalance dynamometer to measure drag force, lateral force, yaw moment, roll moment, andheave and pitch motions. Various stages of this work are presented in the text. The main steps of this activity are to design, prototype,and install strain gauges, and eventuallycalibratethem. Using this procedure, implementing the relevant criteria, the appropriate measures of the strain were selectedmore on the basis of recommendations of professional bodies.Material selection of suitable metal machining and construction work is done. Next, the strain meters were installed onthe balance. After equipment calibration, dynamometer is ready for the ultimate test in towing tank.

Keywords: *Towing tank tests- dynamometer, six-component balance, strain gaugecalibration*

INTRODUCTION

Despite considerable progress in the field of computer aided design and manufacturing (CAD/CAM)has emerged for surface and subsurface vessels, results from these programs haveto be verified by experimental data. In fact, the design of surface and sub-surface vessels through the integration of practical tests on models of vessels in test basins and towing tankstogether with the results of numerical simulations are accomplished. Thus modeltestis a part of concurrent engineering in ship design (Elvekrok, 1997).

Long agothese model tests in different countries were initiated. A brief review may be found in (Bertram, 2000), and the extensive methods are described in (ITTC, 2017). Design and identification of vessels using physical models are verified and validated. Modeling andhydrodynamictests are always key areas in the field of marine engineering (Lewis, 1988). In order to achieve the behavior and movements of vessels and marine structures at the design stage, a test model is used. As the first step, model of the vessel according to the similarity rules, which is fully described in the following sections, isprepared. After adjusting the model floatation, test set-up including environmental conditions are applied (Lyons, *et al*., 1983). In order to perform various tests on the model, a carriage for direct towing, a planar motion mechanism for lateral and yaw motions and other facilities are employed.

The towing tank that is discussed in the present research has length of about 25 meters, width of 2.5 m and depth of 1.5 meters. Ship model are towed with different velocities along the tank

Corresponding Author Email: f.azarsina@srbiau.ac.ir*

and thus flow conditions around the model is observed at different speeds. Fig. 1 showsa view of thetowing tank with gear systems engineering.

MATERIALS AND METHODS

Full details of the dynamometer areexpressed in this section Fig. 2 shows an overview of the system.

The first part of the system is related to the connection of the carriage and to keep a sensor head aligned with it.Because of the fixed connection screws of the gear system and also specified heave sensor layout, the design of the parts must be carefully considered and be proportionate to the size of the other equipment.In other words, to place screw holes, a large opening between the upper drive arm and the heave sensor is embedded.Additional parts on the disk perform thetask of keeping sensors on the system.

The second part of the system is the lower disk.This disk after connecting to the drag force sensor is connected to the third disk as will be explain later.With respect to the second disk, the total force that is exerted on themodelis sensed here.In order to measure the sway force, the mechanism which is embedded in this disk will be used as well.

Additional parts on the diskperform the task of keeping sensors on the system. The third part is a disk holder that is part of the drag load cell and links the relationship between a second hard disk and yaw moment disk.The fifth disk is mounted at the end of the mechanical system will be used to maintain the mechanisms for measuring the roll moment.

Load cell sensor converts the force into an electrical voltage. Four strain gauge load cells are often made up of wheatstone bridge (see Fig. 3).Strain gauge load cell can be two (half-bridge), as well as a strain gauge (quarter-bridge). Load-cell deals with the electrical signal output voltage, often within a few millivolts and for the need to amplify it so that the output voltage is proportional to the force applied.

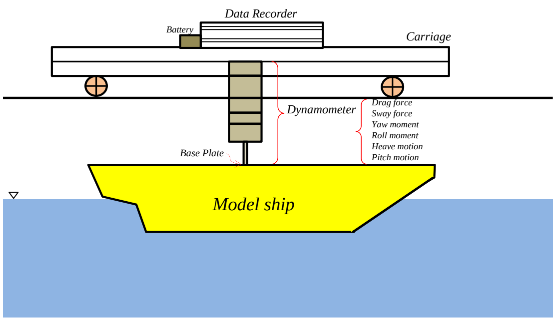

Fig. 1: Side view of the towing tank, model, systems and dynamometer operation

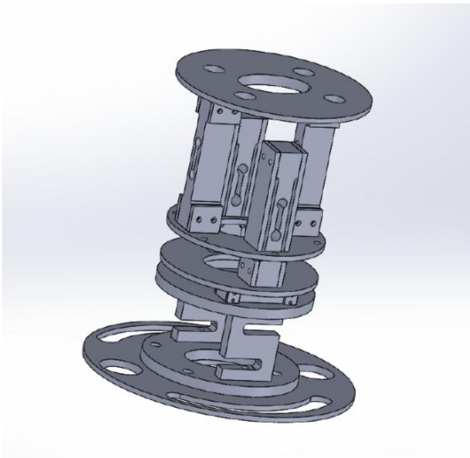

Fig. 2. Overview of dynamometer

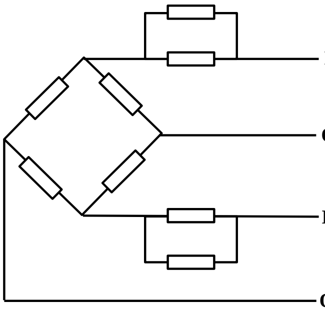

Fig. 3: An example of the strain gauge wheatstone bridge arrangement

Load cells are classified into two types:bending and tensile. The difference is in the way these two types measurethe force. A bending type load-cell is seen in Fig. 4 which is the type used in this report.

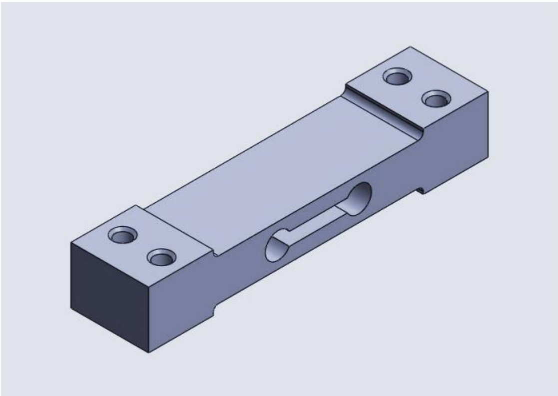
Fig.4: load cell to measure bending force

There are different ways to measure the position. Linear variable differential transformer (LVDT) is used in this report to measure the very small displacements. Linear potentiometers for measuring displacement along a straight line and rotary potentiometers (position) are used to measure rotational movements.

In this section, due to the limitations discussed previously, and the accessible facilities in the domestic market, selection of equipment is reported.

- A bending load cell to measure the drag of 10 kg is used.
- Also, in order to measure the swaya bending load cellof 10 kg.
- As well as to measure the yaw moment two 5 Kg load cellsare used so that the position of the bendingload horizontally passthrough there.
- In order to measure theroll moment tensile load cell of 25 kg is used.

Construction of 6-component dynamometer and its calibration is highlight briefly. After designing and checking final workshop plans to the software, the corresponding G-code and M-Code is sent to CNC machine, milling machine and CNC then takes raw material to machine parts. After preparingdisks as described above, load cell are installed, the sensors and cabling are assembled, and finally dynamometer calibration and final testing is done in thetowing tank.

RESULTS AND DISCUSSION

To calibrate the measurement tools, the force arms must be connected to the system. We selected a number of different weights so that the up and downs in inputsdefine force measurement range.The different weights to the two axes measuring drag and sway force were entered,and the resulting outputs were read. After trying all the steps above to test the accuracy of the calibration of force and arbitrary inputs, variations were observed in the software. The accuracy of the software calibration is done properly otherwise this calibration process was replicated. Fig. 5 shows the manufactured dynamometer during calibration. Table 1 present the range of measurement and accuracy of the 6-component balance. Also Fig. 6 shows the dynamometer as it is connected to a ship model.

Test results in calm water straight-ahead towing is seen in Fig. 7. The normal relation between the drag force and the towing speed squared is observed. This is a benchmark test and the results verify the correctness of the measured force.

Figs. 8 and 9 respectively show the drag force and maximum pitch angle of the same model in waves. Wave amplitude is 2 cm, towing speed is 0.64 m/s and wave lengths vary between 0.8 to 1.3 meters.

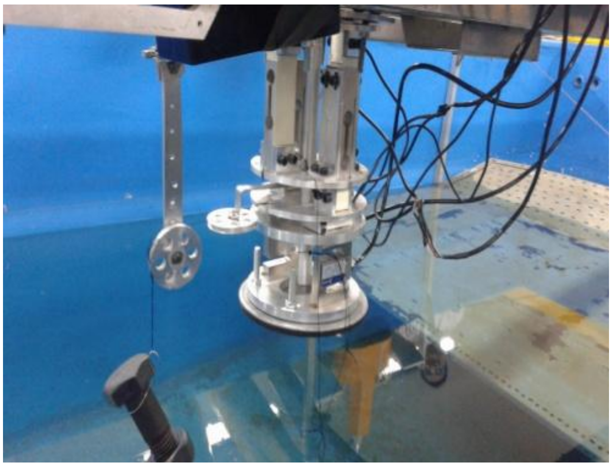

Fig.5: View of sensor calibration for drag force

Table 1: Range of application and accuracy of the 6-component balance

Component	Range of application	Accuracy
Drag force	0.001 to 2 kg	0.1 kg
Sway force	0.001 to 1 kg	0.1 kg
Yaw moment	0.005 to 1kg.m	0.1 kg.m
Roll moment	0.005 to 0.5kg.m	0.1 kg.m
Heave motion	±5 cm	0.1 cm
Pitch motion	±20 deg	0.5 deg

Fig.6: View of the dynamometer and model under towing carriage

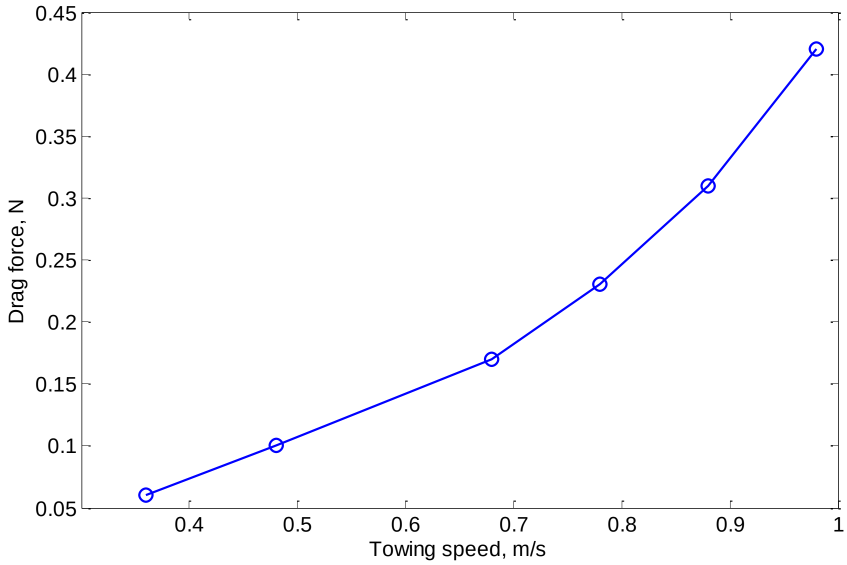

Fig. 7: Resistance curve vstowing speed for a benchmark displacement vessel

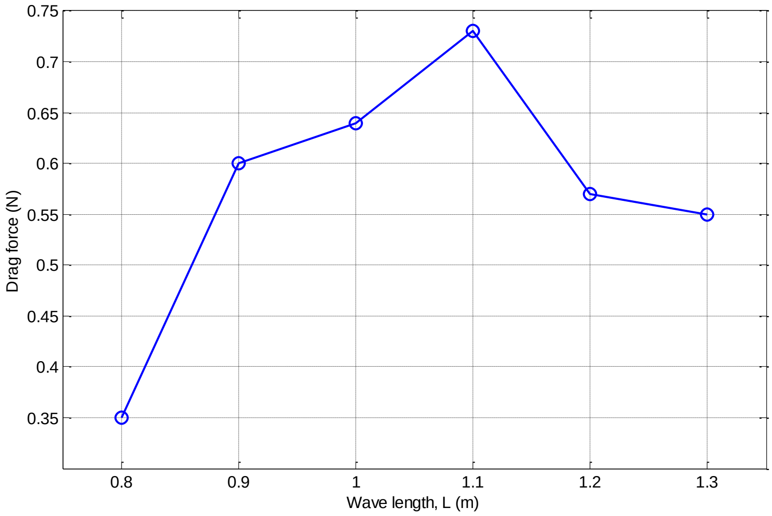

Fig. 8: The resistance curve of a displacement vessel with different wavelength with a constant speed of 0.64m/s andwave amplitude 2cm

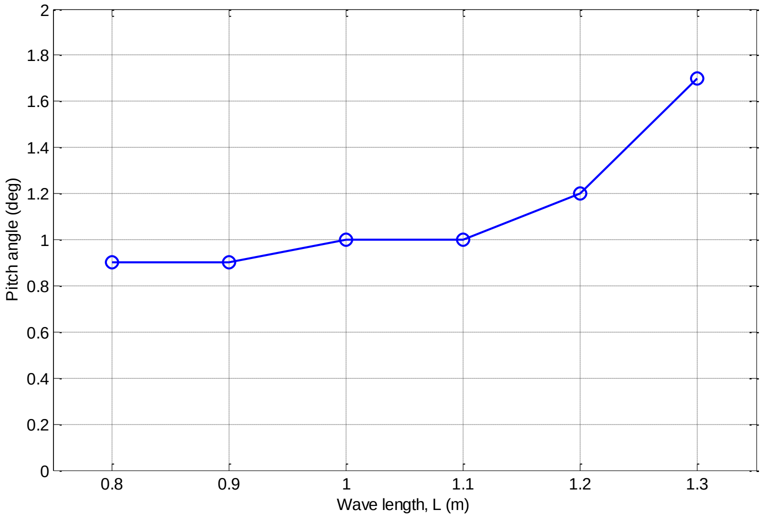

Fig. 9.The maximum pitch angle of a displacement vessel with different wavelength with a constant speed of 0.64 m/s and wave amplitude 2 cm

CONCLUSION

According to the description in the introduction some outstanding points are:

- This is the first report in Iran about design and manufacturing of a six-component balance.
- The application covers different disciplines and expertise in the field of marine activity.
- Achieving a substantial part of technical knowledge in the fieldcan enhance different test models and their subsequent test results.

Further development of such test facilities can upgrade the level of marine technologies in Iran.

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