Practical measurement of trajectory in open water model tests

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Abstract

The common GPS technology – used at sea or in motor vehicle traffic - does not meet the measurement quality requirements of the present day model tests. It is necessary to use special receivers performing very precise real time measurements. Specialised microprocessor controllers allow to substitute a fallible and inaccurate ship model operator by computers. They guarantee practical execution of precisely defined tasks and their full repeatability. Owing to the coordination of the GPS geodesic technology, computing power of the present day miniature processors and radio communications - test automation, unmanned models, quick analysis of results and control from shore have become feasible.

Keywords: *open water model tests, GPS, practical measurement, trajectory*

INTRODUCTION

Since the beginnings of the model tests, the struggle for precision of measurement systems has been a constant feature and one of serious problems is determining and recording the position of a unit on water.

At first, position of a model during manoeuvring tests was determined in relation to some fixed points on water (buoys, leading marks, poles) and this technique is still used as auxiliary measures.

Then analogue instruments came – optics, photography, film...

One of recording techniques used then were „frame-by-frame" photographs of a manoeuvring model in a defined time interval. A tower was constructed for that purpose in the Ilawa Centre. Photographer would climb up and make a series of model photographs.

Fig.1*. Frame-by-frame photographs of a 105,000 DWT OBO ship model trajectory. Mix of 13 frames.*

Another version of the photographic technique were night photographs. A strong source of light was installed on the manoeuvring model and the ship model motion trajectory was marked on the photographic plate.

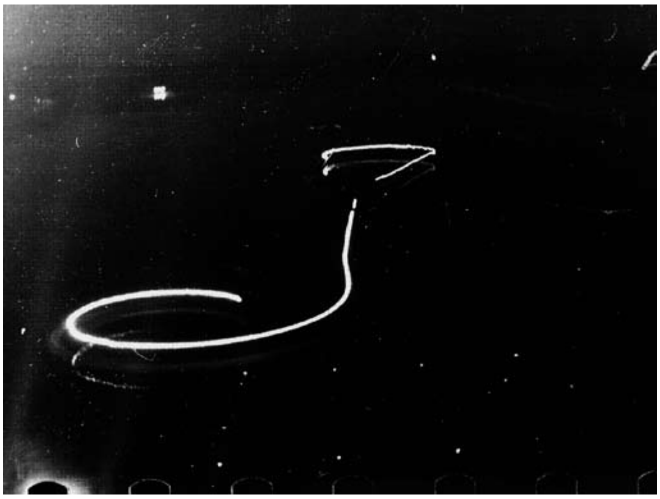
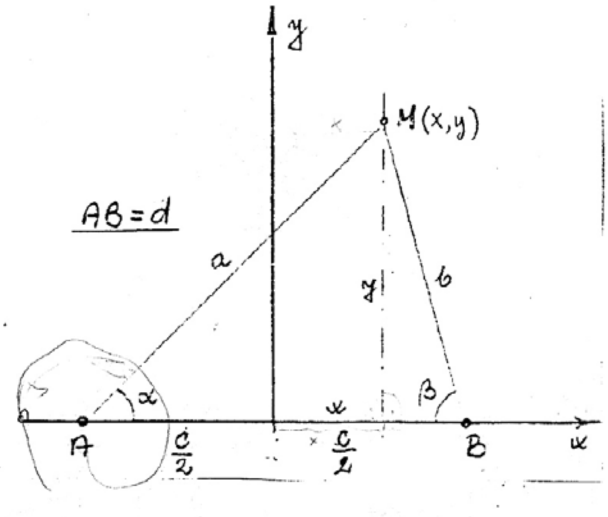


Fig.2. *Night photographs of model tests, 29.08.1977. Turning manoeuvre test.*

An example of tests of a 105,000 DWT OBO ship performed in 1977 is shown in Fig. 2.

As it can be seen, buoys with lights were placed in the test



Drwg. 1. *Measurement principle of the model trajectory*

area and the model position was oriented in relation to them, which allowed later analysis of the manoeuvring qualities.

The accuracy of those measurements was approximately one meter. Therefore, at the times of the development of electronics the method of angle measurements was implemented.

Principle of operation of the electronic trajectory measurement systems

Calculation of the coordinates of a tested object was performed by the mathematical method of intersection, consisting in measurement, from two points A and B ashore, of the direction angles α, β to the model (Drwg.1).

With known length of base C, the model M position coordinates (x, y) can be determined. In the system of coordinates shown in Drwg. 1, position of the model M (x, y) will be

$$x = \frac{c}{2}\left(\frac{tg(\beta) - tg(\alpha)}{tg(\alpha) - tg(\beta)}\right) \quad y = c\left(\frac{tg(\beta) \times tg(\alpha)}{tg(\alpha) + tg(\beta)}\right)$$

expressed by the formula:

Measurements of angles α, β were performed, at different times, visually (by means of all sorts of telescopes) or electronically (infrared cameras). Initially the tracking system was manual, with the use of special levers or gears, in the last version electric motors were used. The angle measurement transducers also changed, from electric selsyns to the optical Gray code pulse counters, in order to reduce the measurement error.

History of the trajectory recording systems

The first model bearings were taken by means of an ordinary sight with a sighting notch, then by means of special levers (arms) the measurement was transferred directly to paper on a drawing desk. Also the technique of plotting the measurement points on paper evolved, first it was only a pen (Fig. 3) and then an electric spark from generators (Fig. 4).

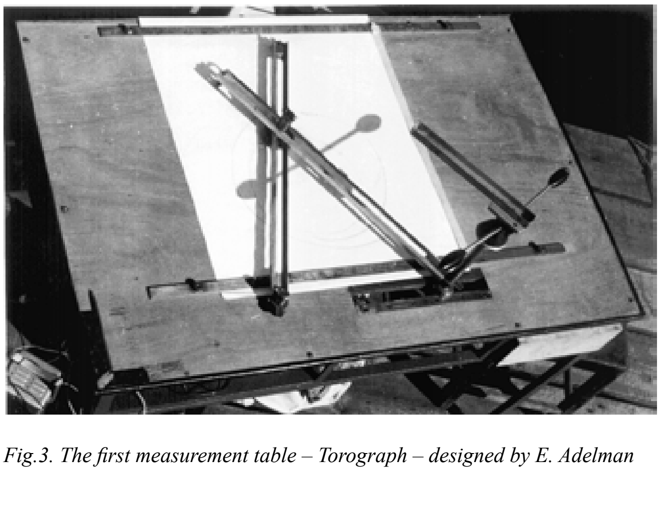


Fig.3. The first measurement table – Torograph – designed by E. Adelman

The improved version of torograph (Fig. 4) had optical telescopes for tracing the model.

The direct measurement arm was on the paper. Another tracing arm, controlled by a follow-up selsyn, was under the paper.

High voltage pulse from the generator burnt model motion traces in the paper at the crossing point of the two arms.

***Fig. 4.** Improved version of torograph with optical telescopes and trace burning*

At a 41.5 m distance from the main torograph table, operator observed the model through a telescope and positioned the parent selsyn (Fig. 5). The selsyn electrically transmitted the directional angle information to the tracking device in the torograph table and the position was printed.

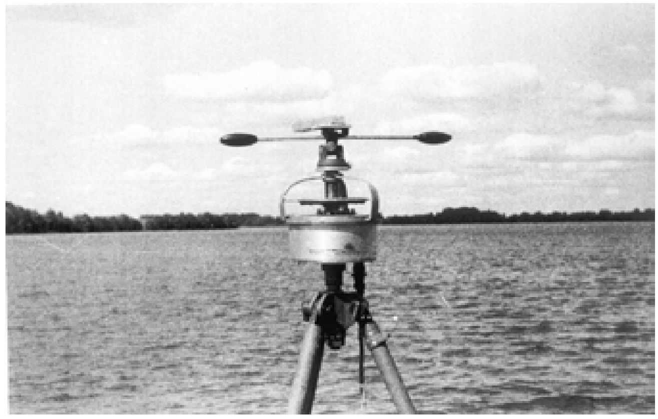


***Fig. 5**. Parent selsyn transmitting angle information – first version without telescopes*

The next improvement of the torograph in 1988 was replacing the selsyn by an electronic angle transducer and collecting data in a Z80 type computer. But observation was still performed by means of an operator-controlled telescope.

***Fig. 6.** Model tracking point with an optical telescope and angle transducer*

The transducer data were analysed in the XT personal computers and the first automatically plotted trajectories were produced (Fig. 7).

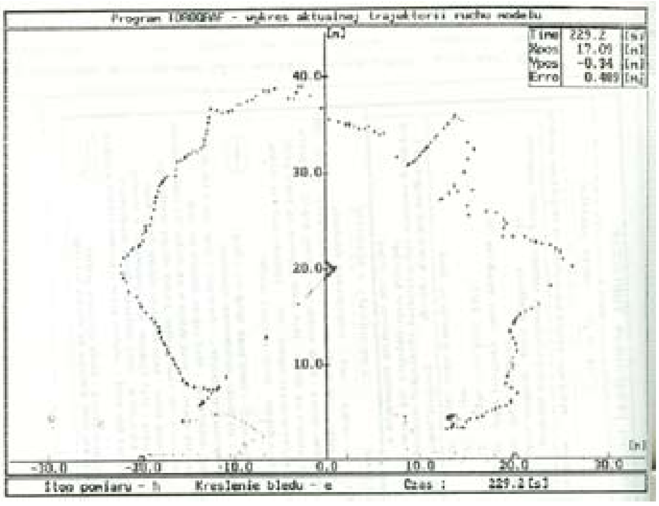
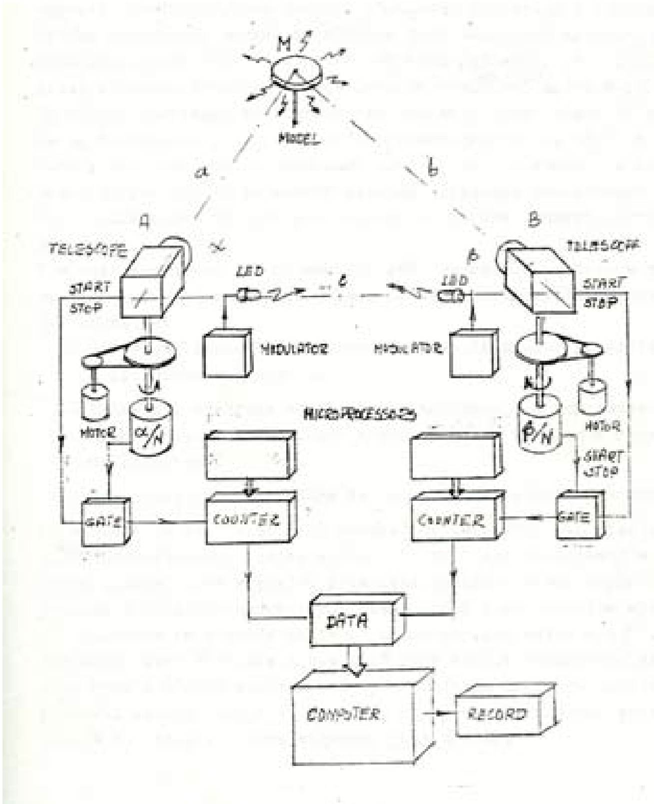


Fig. 7. First computer printouts of trajectories obtained with the angle transducers

Full automation of the bearing taking process was achieved in 1990 when optoelectronics were used for model tracking. The system was built in the Optoelectronics Department of the Warsaw University of Technology Telecommunication Institute. The object tracking was performed with two direction finders with movable telescopes, sensitive to infrared of a specific spectrum and frequency (Fig. 8).

***Fig. 8**. Fully automated model tracking stand*

The infrared radiator was placed on the model and rotating telescopes tracked its position. The angle transducer, coupled with the telescope, was sending information on the model angle and an AT286 computer recalculated it into the model position. The operating, visualization and data recording system was developed in the Foundation for Navigation Safety and Environmennt Protection. Block diagram of the system is presented in Drwg. 2.

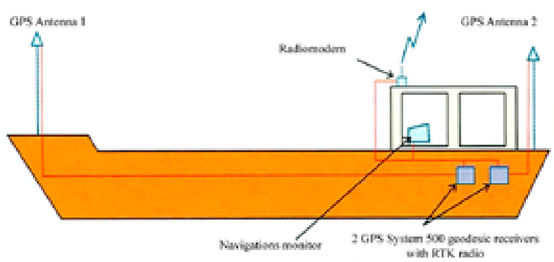


Drwg. 2. Recent fully automated version of torograph

The angle transducer precision was electronically improved and bearing angles were given with 1.8' accuracy. A satisfactory quality of the model position measurement was achieved, at a 20-30 cm level.

Present day research tracking systems

The present day GPS receivers operating in the Real Time Kinematic (RTK) mode give a 3D position determination precision at an 1 cm level. Installing two GPS RTK receivers on a ship model allows to determine the ship position and orientation. Position may be displayed currently on the ship model and that information may be transmitted, through a radiomodem, to the main control stand. The first design of such system is shown in Drwg. 3.



Drwg. 3. First version of GPS SR530 receiver-based tracking system

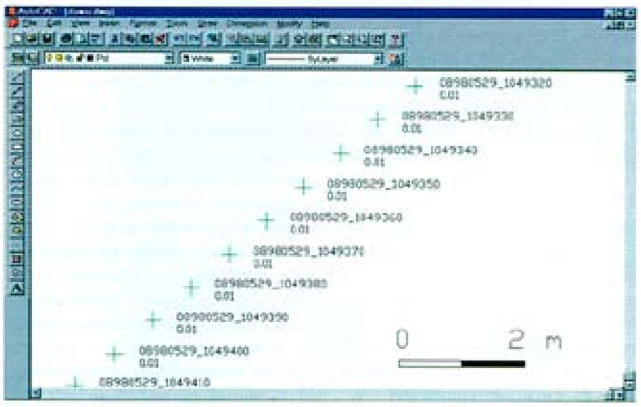
The first tests were carried out in the Foundation for Safety of Navigation and Environment Protection on 29.05.1999.

All the at that time available GPS receivers (Leica, Trimble, Zeiss and Aztech) were installed on the model, which was full of the GPS antennas – Fig. 9.

Leica of Switzerland introduced a new generation of the GPS System 500 geodesic receivers. This new receiver solution allowed to determine position in the RTK mode and set a new satellite geodesy standard in the GPS systems. The new CleartrackTM Technology ensured higher accuracy even in very difficult conditions, e.g. wooded lake shores.

Fig. 9. *Testing of various GPS systems*

Measurement results from the Leica GPS System 500 were converted to the DXF format and imported to Auto-CAD for presentation. A section of the tracking path, displayed in Auto-CAD, is shown in Drwg. 4.



Drwg. 4. *A GPS SR530 model trajectory displayed in Auto-CAD*

Each model position is displayed with a cross symbol and it's description contains measurement time and accuracy in meters. Along the whole path, System 500 delivered data every 1 second with an 1 cm accuracy.

This is a satisfactory result for the contemporary open water model tests.

The latest GPS positioning system

The system has been developed in the Foundation for Safety of Navigation and Environment Protection. It consists of GPS receivers, gyrocompass, radiomodems, an MC68000 deck computer and a base PC for data display and recording.

The most recent Leica series 1200 GPS receivers are equipped with the newest generation AX1202 dual frequency GPS antennas, designed with the use of new military technologies and characterised by a sub-millimetre drift of the phase centre, very good resistance to the reflected and mispolarised signals and also improved tracking of low satellites. The new Leica GX1230 receivers are adjusted also to operation in the VRS and FKP virtual reference station system. They will be adjusted to receiving corrections from the being developed ASG-PL Polish reference network. When the GPS system reaches the configuration allowing to receive new L2C and L5 signals, the receivers will be adjusted to operation with those frequencies. At present, a too small number of satellites does not allow to perform measurements with those frequencies and they are not used in measurements.

The Leica GX1230 receivers are adjusted to receive corrections from the WASS/EGNOS satellites.

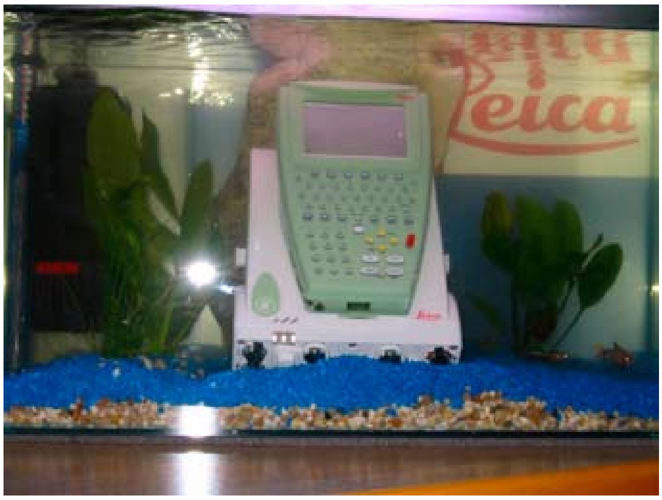


Fig. 10. *New Leica GX1230 GPS during an underwater test*

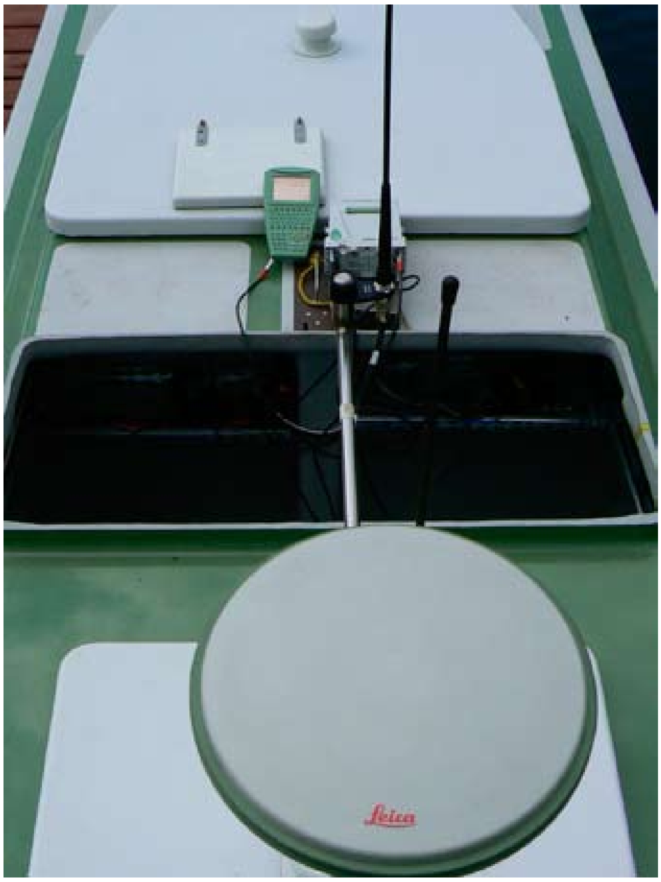


Fig. 12. *GX1230 system installed on a model*

The new GX1200 receivers have an IP67 dust and watertightness standard (temporary submergence to 1 m depth), which makes them suitable for operation in most difficult field and weather conditions. A new magnesium alloy casing makes the receiver resistant to fall from 1 m height on a hard surface.

The new GX1230 set allows to work in the GPS RTK real time technology and in the static mode and to achieve the vector measurement accuracy of 5 mm + 0.5 ppm.

The test system consists of the GPS GX1230 for position recording and an Anschutz STD22 gyro-compass for model direction orientation. The analogue-digital transducers provide information on the rudder position, engine operation parameters, velocity in relation to water, thrusters etc.. All the data are collected in a PC, displayed on a monitor installed on the model and sent via a modem to the observation centre.

In the foreground can be seen a dual frequency GPS AX1202 antenna, behind it on the same mast two radio antennas, the first for receiving the GPS correction to the RTK system, the second for data transmission to the shore. Further on deck is a GX1230 receiver and a programming terminal.

Introduction of new methods of the test model position recording and common use of the PC-class computers caused changes in the test model control and measurements. Loop and magnetic recorders were no longer used and the man-controlled manoeuvring were abandoned. One of the first changes was introduction of the remotely controlled models in the model tests of free motion on waves.

The control system elements were based on ready made remote control devices and miniature own design elements - a strong steering gear and an electronic power transmission

Fig.13. *Model tests on waves*

system, adjusted to the model scale in terms of power and reaction time. Those elemens were a basis for the measurement system development.

A gyro was used once for heel measurements in free motion on waves. Measurement results were recorded in a prototype miniature magnetic dual-channel recorder. It precisely changed the analogue signals into frequencies. A basic difficulty was very limited space, which forced non-typical solutions.

The wave height measurement with calculation of a mean and effective wave height was taken by means of a wave sounder. The sounder was fully automatized, the measurement process consisted of starting the measurement cycle by radio

Fig. 14. *Steering gear and power transmission system*

Fig. 15. *Miniature magnetic recorder*

and after its completion the results were recorded and the sounder became dormant. Sounder would remain in water in the test area for many days.

Another teaching measurement system was the „Z80" deck measurement system. Measurements included the main engine revolutions, rudder position, bow turning mechanism position, thruster revolutions. The rudder and steering gear control modules were added for tests. Measurement results were

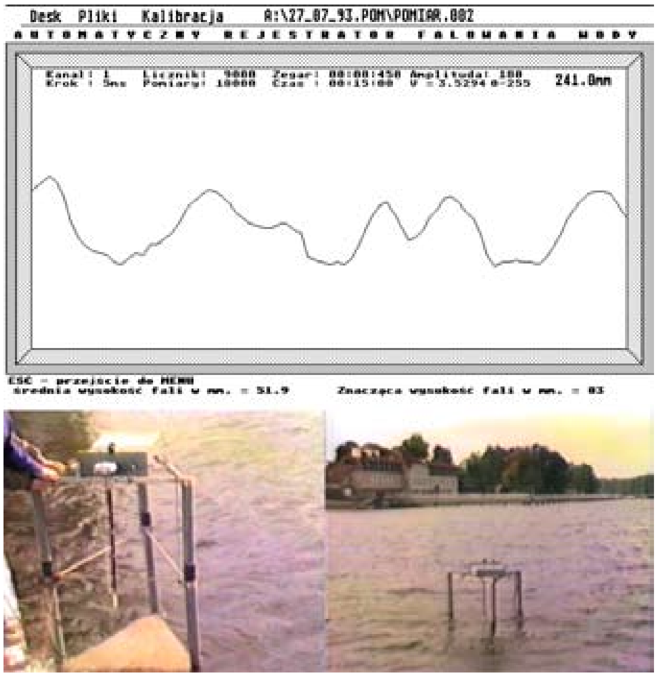


Fig. 16. *Sounder software and view of a sounder on water*

transmitted by radio to the base computer on shore, where the optical positioning system data were also collected. The Z80 measurement system together with the optical bearing finders was used in the catamaran model tests on Jeziorak lake and in the Maritime Academy own investigations where the base computer was on the model and the position data were transmitted from shore to the model.

The system is still in operation and is used for training and presentations of practical measurement methods to the GUT students (the GPS receiver-based positioning system is now in use).

For the needs of a simple spiral test, consisting in stabilising the model angular velocity in changing rudder laying conditions, a precise angular velocity measurement system was developed, based on a precise steering gear and a course gyro with accurate angle measurement. Those devices used GRAY transducers with a 12-bit accuracy. Measurement was considered correct when results of five time intervals, from the current moment on, were identical. Those requirements could be met with an ideal weather, large water space and plenty of time. Even a slight wind or a shallow water had an impact on the model angular velocity.

An outstanding achievement in the measurement system development is the M68 Automatic Measurement System together with its modifications. It is characterised by a modular structure where basic subassemblies and measurement cards are selected according to needs of the standard or extended tests.

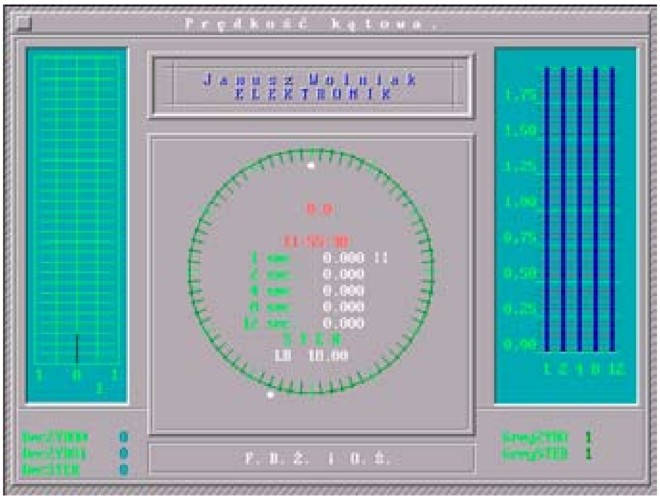


***Fig. 17**. Screen of the angular velocity measurement system*

This system allows to perform manoeuvring tests fully automatically, without human intervention. The system collects measurement data of the test itself and of additional gauges. The collected data may be retransmitted as needed.

***Fig. 18.** Selected subassemblies of the M68 measurement system*

The defined tests are the following:

Circulation test, Exit from circulation test, Circulation with acceleration test, Circulation without propulsion test, zig-zag test, free backing test, crash backing test.

The measurement system allows to carry out non-standard measurements, for instance:

Circulation tests with rudder laid in 45 or 70 degrees and exit from circulation with rudder in 0 position, asymmetrical zig-zag test with departure from course of 10 degrees for rudder laid in 5 degrees.

The set test parameters are rudder direction, rudder angle, reaction to departure angle, main engine revolutions. The parameters are set for a required speed.

The control and measurement accuracy is 12 bits for a range, actual accuracy depends on the steering gear, propulsion system and gauges used.

The system is universal and allows to perform the ship manoeuvring tests either under full remote control without human intervention or locally with base computer on the tested model. System modifications in the form of exchangeable A/D and D/A measurement cards or additional memory cards allow to perform tests on various units. Apart from the standard models, tests were also carried out on twin propulsion and controllable pitch propeller models or models with azipods or combustion engine.

- The operator's supervision includes:
- selecting the test type and parameters,
- directing the model to the measurement area,
- checking the model speed and its possible correction,
- switching the system to the automatic manoeuvring test mode,
- supervising proper execution of the test,
- normal or emergency completion of the automatic manoeuvring test.

Modified versions of the M68 Automatic Measurement System were used as a basis for the development, for teaching purposes, of tug simulators on the training models.

***Fig. 19.** View of the models during tests*

Combining the teaching and research applications allowed to use the teaching systems with properly selected measurement parameters for research purposes. An example is the tug operation supervision system with additional control and measurement channels, used by a research group from the Maritime Academy.

The present measurement system allows to trace the course of experiment on the model and in the measurement centre on shore. Software ensures immediate analysis of measurements,

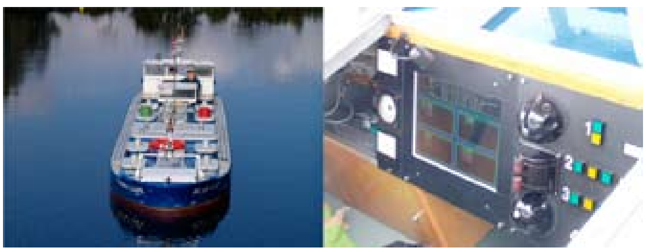
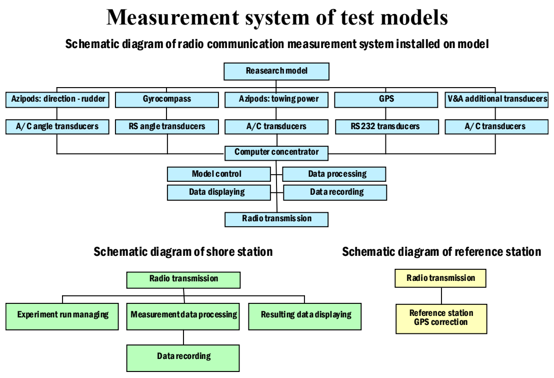
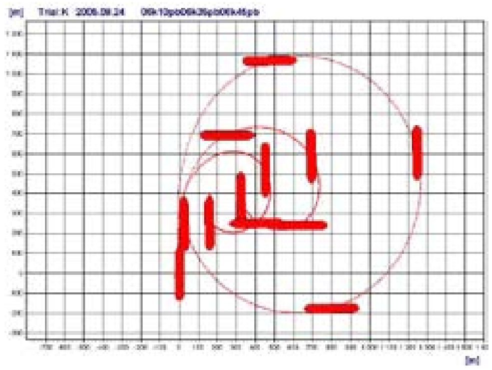


***Fig. 20.** Model with a teaching system prepared for measurements*



Drwg. 5. *Block diagram of an up-to-date test model measurement system*

storing the results and presenting them on paper or on any other data medium - Drwg. 6.

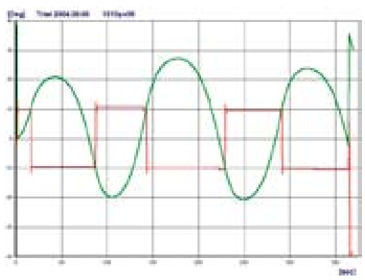


Drwg. 6. *Trajectory diagrams generated by the positioning system – gas carrier model 10o, 35o, 45o turning test*

The GPS position data, gyrocompass data and the MC6800 controller information are collected in the deck computer, which performs the following functions, depending on the type of measurement:

- steering the model (in the zig-zag test, Drwg. 7),
- sending information to shore (radio modems),
- data display for the model operator,
- preliminary data recording.

The system is now used in everyday operation of the Ship Handling Centre in Ilawa on Silm lake.



Drwg. 7. *Deck equipment diagrams generated by the system – $10^o/10^o$ zigzag test*

Future development of research systems and popular bearing taking systems

Commonly used bearing taking systems, depending on a version, achieve positioning accuracy up to 3 m.

Historically, it has been as follows:

- 100 m: position determination accuracy up to 2 May 2000, when the position access limiting signal was switched off,
- 10 m: practical accuracy achieved by the undisturbed GPS signal receivers,
- 5 m: GPS accuracy achieved with a DGPS differential correction signal receiver,
- 3 m: accuracy achieved with a WAAS/EGNOS signal receiver,
- 0.01 m: accuracy achieved with a local reference station signal receiver.

Drwg. 8. *Accuracy of the GPS systems*

At present, the accuracy of specialist systems is 5 mm. These are specialized geodesic receivers, e.g. Leica GX1230, using a local reference station signal. Such systems are very expensive and configuration is taylor-made for a specific application.

The future belongs to the European Galileo system, which is planned to be fully operational in 2010. Galileo is by definition a civilian system, controlled by an international team of specialists to guarantee continuity of its operation. The present GPS or GLONASS systems are of a military origin and they do not guarantee a correct and continuous operation. Galileo will make the satellite signals available in 95% of the urban areas (now the GPS is capable of covering only 50% of those areas). The system will also offer greater transmission band widths, ensuring better accuracy and stronger signal. This will allow to use satellite navigation also in buildings and in tunnels.

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