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Foreword

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The procedures used to develop this document and those intended for its further maintenance are described in the ISO/IEC Directives, Part 1. In particular the different approval criteria needed for the different types of ISO documents should be noted. This document was drafted in accordance with the editorial rules of the ISO/IEC Directives, Part 2 (see www.iso.org/directives).

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For an explanation on the meaning of ISO specific terms and expressions related to conformity assessment, as well as information about ISO's adherence to the WTO principles in the Technical Barriers to Trade (TBT) see the following URL: Foreword - Supplementary information

The committee responsible for this document is ISO/TC 8, *Ships and marine technology*, Subcommittee SC 6, *Navigation and ship operations*.

Annex A is for information only and Annex B forms detailed test methods.

Introduction

An electronic inclinometer is an electronic device that provides information about roll period, roll amplitude, and heel angle of the ship. Electronic inclinometers are intended to support decision-making processes on board in order to avoid dangerous situations as well as assist in maritime casualty investigation. The requirements in this Publicly Available Specification take into account human factors, ergonomic principles, and advances in technology.

Ships and marine technology — Navigation and ship operations — Electronic inclinometers

1 Scope

This Publicly Available Specification specifies the performance requirements, methods of testing, and test results of electronic inclinometers required by the performance standard, IMO resolution MSC.363 (92) in addition to the general requirements contained in resolution A.694 (17) and is associated with IEC 60945.

The electronic inclinometers provide information about actual heel angle, roll amplitude, roll period to support decision-making process on board in order to avoid dangerous situations as well as to assist in maritime casualty investigation. The electronic inclinometers are mainly composed of a set of sensors, a signal processor, a display, an input device, and an interface to other systems.

It does not apply to the electronic inclinometers installed for purposes, which are outside the scope of this Publicly Available Specification, e.g. monitoring of cargo status.

Where a requirement in this Publicly Available Specification is different from IEC 60945, the requirement in this Publicly Available Specification takes precedence.

NOTE All requirements that are extracted from the recommendations of IMO Resolution MSC.363 (92), performance standards for electronic inclinometers, are printed in italics and the resolution and paragraph numbers are indicated in brackets.

2 Normative references

The following documents, in whole or in part, are normatively referenced in this document and are indispensable for its application. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

IEC 60945, *Maritime navigation and radiocommunication equipment and systems — General requirements — Methods of testing and required test results*

IEC 61162-1, *Maritime navigation and radiocommunication equipment and systems — Digital interfaces — Part 1: Single talker and multiple listeners*

IEC 61162-2, *Maritime navigation and radiocommunication equipment and systems — Digital interfaces — Part 2: Single talker and multiple listeners, high-speed transmission*

IEC 61162-3, *Maritime navigation and radiocommunication equipment and systems — Digital interfaces — Part 3: Serial data instrument network*

IEC 61162-450, *Maritime navigation and radiocommunication equipment and systems — Digital interfaces — Part 450: Multiple talkers and multiple listeners — Ethernet interconnection*

3 Terms and definitions

For the purposes of this document, the following terms and definitions apply.

3.1
actual heel angle
momentary angle of roll referenced to a levelled ship to port or starboard side

[SOURCE: IMO MSC.363 (92) Paragraph 3.1]

3.2
analogue type display
display that shows actual heel angle, roll amplitudes, and roll peak hold values in a continuous way, such as by means of an arrow pointer and graduated scale

3.3
digital type display
display that shows actual heel angle, roll amplitudes, and roll peak hold values in the form of numbers

3.4
display
means by which the roll behaviour of the ship and the state of the electronic inclinometer system is presented to an observer

3.5
inspection equipment
equipment for testing the performance of the electronic inclinometer

3.6
reset function for roll peak hold value
function for resetting roll peak hold values to zero and for recording reset date [month, day, and year] and time

3.7
roll amplitude
maximum values of heel angle to port or starboard side

[SOURCE: IMO MSC.363 (92) Paragraph 3.1]

3.8
roll period
time between two successive maximum values of heel angle on the same side of the ship

[SOURCE: IMO MSC.363 (92) Paragraph 3.1]

3.9
roll peak hold value
maximum values of roll amplitude to port or starboard side from the last reset

3.10
rolling
motion around the longitudinal axis of the ship

Note 1 to entry: Positive roll is starboard down.

[SOURCE: IMO MSC.363 (92) Paragraph 3.1]

3.11
zero crossing method
zero crossing method is the way for measuring wave period by using a zero crossing which is a point where the sign of a measured value (roll angle) changes (e.g. from positive to negative)

4 Requirements

4.1 General

Users of this Publicly Available Specification shall note that while attempting to implement the requirements, they shall ensure compliance with such statutory requirements, rules, and regulations so as to be applicable to the individual ship concerned.

4.2 Functionality

[IMO MSC.363 (92) Paragraph 1.2] *The electronic inclinometers* shall *in a reliable form*

a) determine the actual heel angle with the required accuracy,

b) determine the roll amplitude with the required accuracy,

c) determine the roll period with the required accuracy,

d) present the information on a bridge display, and

e) provide a standardized interface to instantaneous heel angle to the voyage data recorder (VDR).

4.3 Information

4.3.1 Actual heel angle and roll amplitude

[IMO MSC.363 (92) Paragraph 4] *Electronic inclinometers* shall *be capable of measuring the actual heel angle and determining the amplitude of the rolling oscillation of the ship over a range of ±90 degrees.*

4.3.2 Roll period

[IMO MSC.363 (92) Paragraph 5] *Electronic inclinometers* shall *be capable of measuring the time between the maximum values of the rolling oscillation and determining the roll period over a minimum range of 4 to 40 s.*

If enough precision is not attained, the period may be measured by the "zero crossing method".

4.3.3 Roll peak hold value

Electronic inclinometers may optionally record the roll peak hold values on both sides and present them on any kind of display.

If optional recording of the roll peak hold values is provided, electronic inclinometers shall have a mean of manually resetting the roll peak hold values by a single operator action.

If necessary, the following sentences may be provided for the reset of roll peak hold value:

$–TXT,01,01,01,EI_RPHVReset_yyyy_mm_dd_oo_nn_ss*hh < CR > < LF > (see IEC 61162-1)

where:

— "yyyy" is reset year.

— "mm" is reset month.

— "dd" is reset day.

— "oo" is reset hour.

— "nn" is reset minute.

— "ss" is reset second, and

— "hh" is check sum.

— TXT (See IEC 61162-1).

4.4 Display

[IMO MSC.363 (92) Paragraph 7.2] *The actual heel angle to port or starboard* shall *be indicated in an analogue form between the limits of ±45 degrees.*

[IMO MSC.363 (92) Paragraph 7.1.2] *Electronic inclinometers* shall *display the roll amplitude to both port and starboard side with a minimum resolution of one degree.*

Electronic inclinometers may optionally display the roll peak hold value for both sides, port and starboard, with a minimum resolution of one degree and its reset date/time.

[IMO MSC.363 (92) Paragraph 7.1.1] *Electronic inclinometers* shall *display the latest roll period with a minimum resolution of 1 s.*

[IMO MSC.363 (92) Paragraph 7.3] *The display may be implemented as a dedicated display or integrated into other bridge systems.*

4.5 Status indication

The electronic inclinometer system shall include status indications that include, but are not limited to the following:

a) that power is available to the system,

b) that the system is switched on and is ready to use,

c) that the system is switched on but there is a fault on one (or more) sensor(s), and

d) that the system has recorded a measurement of heel angle exceeding a pre-set threshold value.

4.6 Alert

4.6.1 Operational alert

[IMO MSC.363 (92) Paragraph 8.2] *Electronic inclinometers may optionally provide a warning for indicating that a set heel angle had been exceeded.*

Electronic inclinometers that include a heel angle warning function shall have a method of resetting the warning.

Electronic inclinometers that include a heel angle warning function shall have a method of manually setting the threshold value of heel angle.

The operational alert function shall provide display of the warning and may optionally provide the warning by audible and/or visible means.

The inclinometer system should be capable of supporting an interface with a centralized alarm management system.

ALF sentence is used to initiate a warning on other bridge systems when the actual heel angle exceeds the pre-set threshold.

The following sentences shall be provided for the alert communications interface:

Sentences transmitted by the electronic inclinometers

— ALF and ACN (See IEC 61924-2)

Sentences received by the electronic inclinometers

— ACN (See IEC 61924-2)

The following sentence may be provided for the input of a threshold value of heel angle:

$–TXT,01,01,01,EI_RollThresholdAngle_xx_deg *hh < CR > < LF >

where:

— “xx” is the threshold value of heel angle, and

— “hh” is check sum.

— TXT (See IEC 61162-1).

4.6.2 Functional alert

[IMO MSC.363 (92) Paragraph 9.1] *Electronic inclinometers* shall *internally check and indicate to the user if all components are operative and if the information provided is valid or not.*

[IMO MSC.363 (92) Paragraph 10.2] *Electronic inclinometers* shall *have a bidirectional interface to facilitate communication, to transfer alerts from inclinometers to external systems, and to acknowledge and silence alerts from external systems.*

An alert shall be provided and be output on the following conditions:

— malfunction of the electronic inclinometer sensor(s),

— failure of the power supply,

— failure of the interface with other important systems (VDR, INS, Alarm management system, etc.), and

— heel angle information displayed is invalid.

The alert shall conform to the presentation and handling requirements of Bridge Alert Management [IMO Res. MSC.302 (87)]. When an Integrated Navigation System (INS) is fitted, a suitable interface shall be provided for alert communications with an Integrated Navigation System [IMO Res. MSC.252 (83) and IEC 61924-2].

The following sentences shall be provided for the alert communications interface:

Sentences transmitted by the electronic inclinometers

— HBT (See IEC 61162-1)

— ALC, ALF, and ACN (See IEC 61924-2)

Sentences received by the electronic inclinometers

— HBT (See IEC 61162-1)

— ACN (See IEC 61924-2)

4.7 Interface

[IMO MSC.363 (92) Paragraph 10.1] *Electronic inclinometers* shall *comprise a digital interface providing actual heel angle information to other systems like, e.g. the voyage data recorder (VDR), with an update rate of at least 5 Hz. Electronic inclinometers* shall *also comprise a digital interface providing the displayed information of roll period and roll amplitude* (see 4.3).

[IMO MSC.363 (92) Paragraph 10.3] *The digital interface* shall *comply with the relevant International Standards* IEC 61162-1 and, IEC 61162-2 or IEC 61162-450 or IEC 61162-3 as amended.

4.8 Continuous operation

The equipment shall be capable of continuous operation under conditions of vibration, humidity, change of temperature, and variations of the power supply, as described in IEC 60945.

4.9 Power supply

[IMO MSC.363 (92) Paragraph 12] *Electronic inclinometers* shall *be powered from the ship's main source of electrical energy. In addition, it* shall *be possible to operate the electronic inclinometers from the ship's emergency source of electrical energy.*

5 Accuracy

5.1 Actual heel angle, roll amplitude, and roll period

[IMO MSC.363 (92) Paragraph 6.1] *Electronic inclinometers* shall *provide the data with sufficient accuracy for a proper assessment of the ships dynamic situation. Minimum accuracy of the measurements* shall *be 5 % of reading or ±1 degree whichever is the greater for angle measurements and 5 % of reading or ±1 s, whichever is the greater for time measurements.*

5.2 Acceleration condition

[IMO MSC.363 (92) Paragraph 6.2] *Actual heel angle and time measurement accuracy* shall *not be unduly affected by other linear or rotational movements of the ship (as e.g. surging, swaying, heaving, pitching, yawing) or by transverse acceleration ranging from −0,8 g to +0,8 g.*

The required acceleration condition, 0,8 g, includes the component of the gravitational acceleration.

6 Test methods and required results

6.1 General

Unless otherwise stated in this Publicly Available Specification, the requirements of IEC 60945 shall apply to the electronic inclinometer. To ease the term, EUT (equipment under test) will be used to describe an electronic inclinometer system being tested.

The test arrangement shall consist of the following:

— movable arm which enables rotation of the EUT sensor from the zero degree roll angle position (upright) to the maximum roll angle position (90 degrees) to both starboard and port sides,

— display representing other bridge equipment with which the EUT may communicate, and

— method of generating and transmitting to the EUT recognized NMEA words and sentences.

The EUT shall be arranged so that the heel sensors are secured to the moveable arm, the display is readily observable and there is a suitable connection to permit the transmission and receipt of NMEA messages between the EUT and the inspection equipment.

6.2 Static actual heel angle test

6.2.1 Method of testing

To determine the actual heel angle of the electronic inclinometer statically, the EUT sensor is gradually rotated from the zero degree to the maximum roll angle position on one side and then from zero to maximum on the other side. Outputs of the EUT and the inspection equipment are recorded every five degrees of rotation.

6.2.2 Required test result

Verify that the difference between the angles recorded by the EUT and the inspection equipment shall be within five per cent, or one degree, of the inspection equipment reading, whichever is the larger.

6.3 Dynamic actual heel angle test

6.3.1 Method of testing

To determine the actual heel angle of the electronic inclinometer dynamically, the EUT sensor is gradually rotated from the zero degree to the maximum roll angle position on one side and then from zero to maximum on the other side. The inspection equipment shall also permit the addition of the maximum expected transverse acceleration, 0,8 g, to the top of the arm. Before the test, manufacturers shall provide information on the measurement delays in the EUT. Any measurement delay shall be less than 0,1 second.

The comparison of all measured heel angles between the EUT and the inspection equipment is carried out with randomly selected measured two cycle data in the following two conditions:

— roll period of 4 seconds and roll amplitude of 90 degrees, and

— roll period of 40 seconds and roll amplitude of 90 degrees.

The heel angles of the EUT and the inspection equipment shall be recorded at a frequency of no less than 50 Hz.

6.3.2 Required test result

Verify that the difference between the angles recorded by the EUT and the inspection equipment shall be within five per cent, or one degree, of the inspection equipment reading, whichever is the larger.

6.4 Long term actual heel angle test

6.4.1 Method of testing

To confirm that an integral calculus error in the measured heel angle does not influence performance, a series of small angle dynamic actual heel angle tests are conducted. The sensor of the EUT is swung repeatedly between roll angles of 45 degrees to starboard and 45 degrees to port continuously for no less than 1 day using the inspection equipment.

The heel angles of the EUT and the inspection equipment shall be recorded at a frequency of no less than 50 Hz.

6.4.2 Required test result

Verify that the difference between the angles recorded by the EUT and the inspection equipment shall be within five per cent, or one degree, of the inspection equipment reading, whichever is the larger.

6.5 Roll period test

6.5.1 Method of testing

To confirm that the EUT correctly records the roll period, the sensor is attached to the arm of the inspection equipment and swung 45 degrees to starboard and port. The comparison of all measured rolls periods between the EUT and the inspection equipment is carried in the following two conditions:

— roll period of 4 seconds and a roll amplitude of 45 degrees, and

— roll period of 40 seconds and a roll amplitude of 45 degrees.

6.5.2 Required test result

Verify that the difference between the roll periods recorded by the EUT and the inspection equipment shall be within 5 %, or 1 s, of the inspection equipment reading, whichever is the larger.

6.6 Connections to other equipment test

The connections to other equipment test shall satisfy the requirements of 4.7.

The interface facilities shall be subjected to the tests specified in IEC 61162-1 and IEC 61162-2, or IEC 61162-450, or IEC 61162-3.

6.6.1 Method of testing

The sensor of the EUT is placed on the top of the arm of the inspection equipment. The sensor is then rotated to simulate:

— roll period of 10 seconds and a roll amplitude of 10 degrees for more than 60 seconds.

Observe the actual heel angle output rate.

6.6.2 Required test result

By monitoring the 'HRM' sentence generated by the EUT, verify that the output is updated at least once per 200 ms.

6.7 Display test

The display test shall satisfy the requirements of 4.4.

Two samples of the display are shown in Figure 1 and Figure 2. Figure 1 is a sample of a traditional type electronic inclinometer display and Figure 2 is a sample of electronic inclinometer display for a dedicated display or integrated into other bridge systems. They are just samples for better understanding of the defined values and they do not prescribe display design of the electronic inclinometer display.

6.7.1 Method of testing

The EUT sensor is secured to the test arm of the inspection equipment. If the EUT will be interfaced with additional systems' displays, it shall also be connected to a representative system so that the output can be monitored simultaneously. The sensor is subjected to the following motions:

a) Incline the EUT sensor 10 degrees to starboard and to port;

b) Rotate the EUT sensor at the following pre-determined roll periods and roll amplitudes:

— roll period of 10 seconds and a roll amplitude 10 degrees;

— roll period of 20 seconds and a roll amplitude 20 degrees;

— roll period of 30 seconds and a roll amplitude 30 degrees.

6.7.2 Required test results

a) Test results obtained

— By observation, verify that the actual heel angle value is shown on a dedicated display in an analogue form and to an accuracy of not more than ±5 %, or ±1°, of the actual value, whichever is the greater.

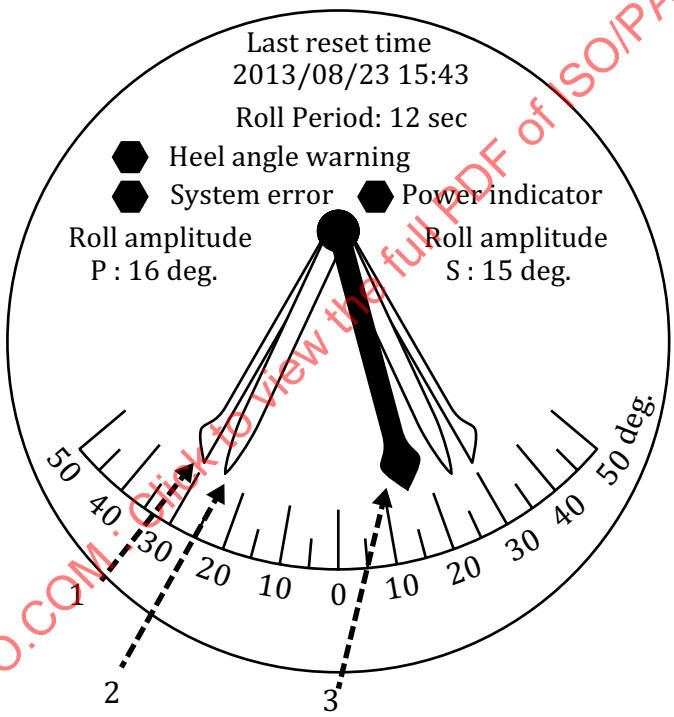
— By monitoring the HRM sentences transmitted by the EUT, and by observing the display of another 'test' equipment interfaced to the EUT, verify that the value of actual heel angle 'told' to the integrated displays of other bridge systems also has an accuracy of not more than ±5 %, or ±1°, of the actual value, whichever is the greater and that the resolution of numeric display is one degree.

b) Test results obtained

— By observation, verify that the roll period and roll amplitude values are shown on a dedicated display to an accuracy of not more than ±5 %, or ±1°, of the actual value, whichever is the greater.

— By monitoring the HRM sentences transmitted by the EUT, and by observing the display of another 'test' equipment interfaced to the EUT, verify that the actual values of roll period and roll amplitude 'told' to integrated displays of other bridge systems has an accuracy of not more than ±5 %, or ±1 s, or 1°, of the actual value, whichever is the larger and that the resolution of numeric display is 1° and 1 s.

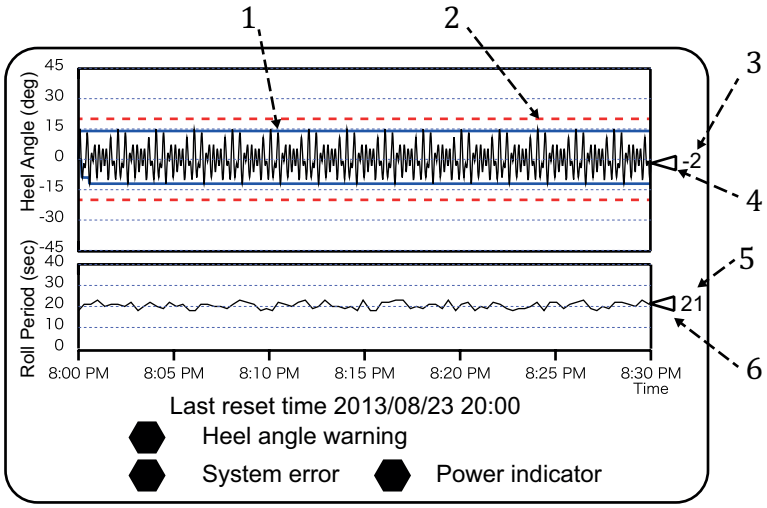
When the measured roll period is less than 4 s, the display should represent the value as "–" and when the period is greater than 40 s, as "++".



Key

1 roll peak hold value
2 threshold heel angle
3 analogue heel angle indicator

Figure 1 — Example of a conventional head up type electronic inclinometer display



Key

1 roll peak hold value
2 threshold heel angle
3 digital heel angle indicator
4 analogue heel angle indicator
5 digital roll period indicator
6 analogue roll period indicator

Figure 2 — Example of an electronic inclinometer display for an integrated conning display

6.8 Status indication test

6.8.1 Method of testing

Connect the EUT to an external power supply and switch it on.

Remove the external power supply from the EUT without switching it off.

6.8.2 Required test results

By observation, verify that the status indicator lamp shows a steady green light.

By observation, verify that the status indicator shows a flashing orange light or if the EUT has no battery the indictor shows a steady red light or no light.

6.9 Operational alert test

The operational alert test shall satisfy the requirements of 4.6.1.

The electronic inclinometer shall provide an operational alert when it has a function for warning to indicate that a set heel angle has been exceeded.

The operational alert function shall provide display of the warning and ALF sentence to initiate a warning on other bridge systems when the actual heel angle exceeds the pre-set threshold.

6.9.1 Method of testing

Perform the following procedures.

a) Set the threshold value to 20 degrees by a manual input device, if available.

b) Or set the threshold value to 20 degrees by transmitting a TXT sentence for setting threshold value of heel angle (defined in 4.6.1) to the electronic inclinometer.

c) Incline the heel sensor to 30 degrees.

d) Silence any warning annunciation provided in the EUT.

e) Transmit ACN sentence to the electronic inclinometer to silence the warning of the electronic inclinometer

f) Acknowledge any warning annunciation provided in the EUT.

g) Transmit ACN sentence to the electronic inclinometer to acknowledge the warning of the electronic inclinometer.

h) Restore the heel sensor to zero degree inclination.

6.9.2 Required test results

Verify the following.

a) The threshold value is shown on the display properly. A TXT sentence (defined in 4.6.1) is transmitted from the electronic inclinometer to show the pre-set threshold value on an integrated display of other bridge systems.

b) The pre-set threshold value is shown on the display properly.

c) The electronic inclinometer initiates a heel angle excessive warning by audible and/or visible means and ALF, ALC, and HBT sentences are transmitted from the electronic inclinometer to other bridge systems to report new warning status (unacknowledged) of the electronic inclinometer.

d) Verify that the audible warning becomes silent and ALF, ALC, and HBT sentences are transmitted from the electronic inclinometer to other bridge systems to report new warning status (silenced) of the electronic inclinometer.

e) Verify that the visual warning becomes acknowledged condition and ALF, ALC, and HBT sentences are transmitted from the electronic inclinometer to other bridge systems to report new warning status (acknowledged) of the electronic inclinometer.

f) Verify that the visual warning becomes acknowledged condition and ALF, ALC, and HBT sentences are transmitted from the electronic inclinometer to other bridge systems to report warning status (acknowledged) of the electronic inclinometer.

g) Verify that the warning display becomes cleared and ALF, ALC, and HBT sentences are transmitted from the electronic inclinometer to other bridge systems to report warning status (normal) of the electronic inclinometer.

6.10 Functional alert test

The functional alert test shall satisfy the requirements of 4.6.2.

6.10.1 Method of testing

Perform the following procedures.

a) Set the electronic inclinometer to malfunction state.

b) Push a button to silence the functional alert on the electronic inclinometer, if available.

c) Transmit ACN sentence to the electronic inclinometer to silence the functional alert of the electronic inclinometer.

d) Push a button to acknowledge the functional alert on the electronic inclinometer, if available.

e) Transmit ACN sentence to the electronic inclinometer to acknowledge the functional alert of the electronic inclinometer.

f) Recover the electronic inclinometer from malfunction state.

6.10.2 Required test results

a) Verify that the electronic inclinometer initiates a functional alert by audible and/or visible means and ALF, ALC, and HBT sentences are transmitted from the electronic inclinometer to other bridge systems to initiate the functional alert on the systems.

b) Verify that the audible functional alert becomes silent and ALF, ALC, and HBT sentences are transmitted from the electronic inclinometer to other bridge systems to report new functional alert status of the electronic inclinometer.

c) Verify that the visual functional alert becomes acknowledged condition and ALF, ALC, and HBT sentences are transmitted from the electronic inclinometer to other bridge systems to report new functional alert status of the electronic inclinometer.

d) Verify that the functional alert display becomes cleared and ALF, ALC, and HBT sentences are transmitted from the electronic inclinometer to other bridge systems to report new functional alert status (normal) of the electronic inclinometer.

6.11 The roll peak hold value test

The roll peak hold value test shall satisfy the requirements of 4.3.3.

6.11.1 Method of testing

Rotate the electronic inclinometer as following conditions.

— Roll period 10 seconds and roll amplitude 10 degrees for more than 60 seconds.

— Roll period 30 seconds and roll amplitude 30 degrees for more than 180 seconds.

— Stop rotating.

6.11.2 Required test results

Verify that the roll peak hold value is shown on a dedicated display and/or HRM sentence is transmitted by the electronic inclinometer to other bridge systems and it includes proper roll peak hold values.

6.12 The reset function of roll peak hold value test

The electronic inclinometer shall provide a manual reset device to initiate reset function with single operator action to users, when it has a function to show roll peak hold values.

The roll peak hold values shall become zero, when the reset function is initiated.

The reset date/time should be recorded and displayed on a dedicated display or an integrated display, when the reset function is initiated.

6.12.1 Method of testing

Push a roll peak hold value reset button of the electronic inclinometer, if available, or transmit TXT sentence (defined in 4.3.3) to the electronic inclinometer to reset the roll peak hold value.

6.12.2 Required test results

Verify the following.

— Both starboard and port roll peak hold values are set to zero. And/or, the reset date/time is set to the time when the reset button is pushed or TXT sentence (defined in 4.3.3) is received.

— TXT sentence (defined in 4.3.3) transmitted by the electronic inclinometer includes proper roll peak hold values and reset date/time.

6.13 Power supply test

It shall be confirmed that the electronic inclinometer is powered from the ship's emergency source of electrical energy, when the ship's main source of electrical energy is unavailable.

7 Installation position

[IMO MSC.363 (92) Paragraph 11] *The installation position of the sensors of the electronic inclinometer* shall *be recorded and made available for the configuration of the voyage data recorder.*

8 Information

The manufacturer shall provide adequate equipment documentation to enable competent members of a ship's crew to operate and maintain the equipment efficiently.

Annex A
(informative)

Relation between transverse metacentric stability and measured natural roll period of ships in wave

To support understanding the use of measured natural roll period in waves and effective GM (the metacentric height of the ship) in decision making of navigating in rough sea, this annex explains the relation between stability and measured natural roll period of ships in wave.

As the GM is considered effective in small heel angles from the upright, typically less than about 10 degrees, the restoring moment of roll motion is expressed as Formula (1) and the equation of roll motion is expressed as Formula (2).

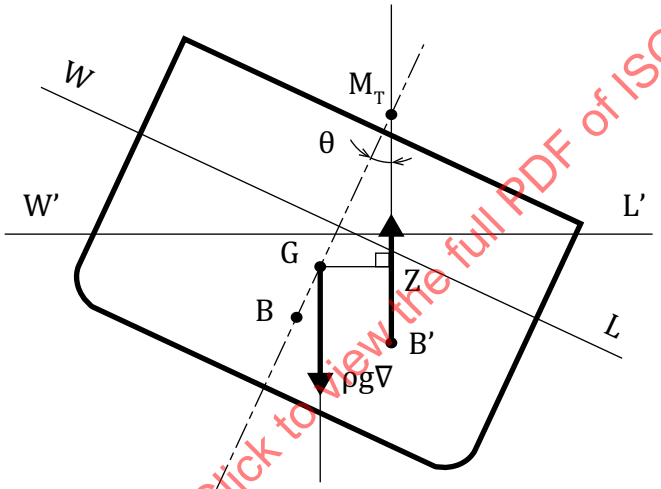


Figure A.1 — Restoring roll moment

$$M = \rho g \nabla \overline{G M_T} \sin\theta = \rho g \nabla \overline{G M_T}\, \theta \qquad \text{(A.1)}$$

where

M is restoring roll moment (Nm);

ρ is water density (kg/m^3);

g is gravitational acceleration (m/s^2);

∇ is displacement (m^3);

$\overline{G M_T}$ is transverse metacentric height (m);

θ is heel angle form the upright (rad).