INTERNATIONAL STANDARD

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Small craft — Electrical/electronic control systems for steering, shift and throttle

Petits navires — Systèmes électriques/électroniques pour le contrôle de la direction, de l'inverseur et des gaz

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Foreword

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International Standards are drafted in accordance with the rules given in the ISO/IEC Directives, Part 2.

The main task of technical committees is to prepare International Standards. Draft International Standards adopted by the technical committees are circulated to the member bodies for voting. Publication as an International Standard requires approval by at least 75 % of the member bodies casting a vote.

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. ISO shall not be held responsible for identifying any or all such patent rights.

ISO 25197 was prepared by Technical Committee ISO/TC 188, *Small craft*.

Small craft — Electrical/electronic control systems for steering, shift and throttle

1 Scope

This International Standard establishes the requirements for design, construction and testing of electrical/electronic steering, shift and throttle and dynamic position control systems, or combinations thereof, on small craft of up to 24 m length of hull.

2 Normative references

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

ISO 8846, *Small craft — Electrical devices — Protection against ignition of surrounding flammable gases.*

ISO 8848, *Small craft — Remote steering systems*

ISO 10133, *Small craft — Electrical systems — Extra-low-voltage d.c. installations*

ISO 10240, *Small craft — Owner's manual*

ISO 10592, *Small craft — Hydraulic steering systems*

ISO 11591, *Small craft, engine-driven — Field of vision from helm position*

ISO 12215-8, *Small craft — Hull construction and scantlings — Part 8: Rudders*

ISO 13297, *Small craft — Electrical systems — Alternating current installations*

ISO 16750-2:2010, *Road vehicles — Environmental conditions and testing for electrical and electronic equipment — Part 2: Electrical loads*

ISO 16750-3:2007, *Road vehicles — Environmental conditions and testing for electrical and electronic equipment — Part 3: Mechanical loads*

ISO 16750-4, *Road vehicles — Environmental conditions and testing for electrical and electronic equipment — Part 4: Climatic loads*

IEC 60068-2-27, *Environmental testing — Part 2-27: Tests — Test Ea and guidance: Shock*

IEC 60068-2-52, *Environmental testing — Part 2-52: Tests — Test Kb: Salt mist, cyclic (sodium chloride solution)*

IEC 60092-507, *Electrical installations in ships — Part 507: Small vessels*

IEC 60533:1999, *Electrical and electronic installations in ships — Electromagnetic compatibility*

IEC 60945:2002, *Maritime navigation and radiocommunication equipment and systems — General requirements — Methods of testing and required test results*

IEC 61000-4-5, *Electromagnetic compatibility (EMC) — Part 4-5: Testing and measurement techniques — Surge immunity test*

IEC 61508 (all parts), *Functional safety of electrical/electronic/programmable electronic safety-related systems*

3 Terms and definitions

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

3.1
electric/electronic steering system
all components, including CPU (central processing unit) and cable harnesses, from the manual steering input device up to and including the device (actuator or electrical motor) regulating the rudder or propulsion unit steering angle

NOTE to entry: It includes the joystick and components, i.e. GPS antennas for dynamic positioning, if installed.

3.2
dynamic-positioning system
computer-controlled system to automatically maintain a craft's position and heading by using her own propulsion systems with or without the assistance of bow or stern thrusters

3.3
electrical/electronic shift and throttle system
all components, including CPU (central processing unit) and cable harnesses, from the shift and throttle input device up to and including the device controlling the shift and speed of engines.

3.4
ignition-protected equipment
electrical equipment designed and tested for use in explosive atmospheres without igniting surrounding flammable gases

3.5
accessible
capable of being reached for inspection, removal or maintenance without removal of permanent structure of the craft

3.6
readily accessible
capable of being reached without the use of tools

3.7
nominal voltage(s)
those commonly used voltages, such as 12 volts, 24 volts, or 36 volts DC

3.8
manoeuvring mode
reduced power mode for manoeuvring, determined by the manufacturer

3.9
cruising mode
power mode above manoeuvring mode up to full power, determined by the manufacturer

3.10
X axis
direction of a craft fore or aft, longitudinally

3.11
Y axis
direction of a craft port or starboard, transversely

3.12
Z axis
axis normal to the X-Y plane

3.13
control head
single oriented device, other than a steering wheel, for the simultaneous control of steering and propulsion

EXAMPLES Joystick, track-ball or slide levers.

3.14
control lever
operator input device for the control of thrust and/or propulsion

3.15
steering helm
operator input device for the control of steering

3.16
joystick
operator input device for the simultaneous control of thrust, steering and propulsion

3.17
helm station
location from which steering, propulsion and thrust can be controlled

3.18
multiple helm stations
more than one location in the boat from which steering, propulsion and thrust can be controlled

3.19
command station
helm station location that is in active control

3.20
portable helm
helm providing a combination of shift or throttle or steering, not permanently affixed to the craft's structure, communicating with the system through wired or wireless means

3.21
propulsion
component or components of thrust that permit a craft's movement in any direction

NOTE to entry: Examples of propulsion-generating devices include outboards, stern drives, pod drives, jet drives, inboards and thrusters.

3.22
radio frequency
RF
frequency within the range of frequencies suitable for utilization in radio communication

3.23
actuator
electromechanical, electropneumatic and/or electrohydraulic device that converts an electrical signal into a mechanical displacement

3.24
thrust
propulsive force from craft's main propulsion system or bow or stern thrusters or a combination thereof in order to move or rotate the craft

3.25
wireless
mode of communication, monitoring and/or control through the use of electromagnetic, acoustic or optical transmission through atmospheric space

3.26
damp area
area where moisture is either permanently or intermittently present

EXAMPLE Bilge, head, galley.

3.27
wet area
area exposed to weather

3.28
interior
protected area inside the craft

3.29
EUT
equipment under test

3.30
performance criterion
standard by which the functional status of an EUT during and after testing is judged

3.31
failure modes and effects analysis
FMEA
procedure in product development and operations development for analysis of potential failure modes

3.32
fail-safe mode
device or feature which, in the event of failure, responds in a way that will cause no harm, or minimize the harm, to other devices and cause no danger, or minimize the danger, to personnel

4 General requirements

4.1 All electronic/electrical components shall be designed to withstand a reversed-polarity connection of the power leads. This shall not render the component inoperable when subsequently connected to the power correctly.

4.2 All electronic/electrical components shall be designed with reverse polarity protection from internal surges.

4.3 DC systems shall comply with ISO 10133. AC systems shall comply with ISO 13297. An acceptable alternative to ISO 10133 and ISO 13297 is given in IEC 60092-507.

4.4 The system shall be energized whenever the propulsion engine(s) are running.

4.5 The system, except for dynamic positioning and displays, shall be fully operational within five seconds after being turned on (powered).

4.6 Multi-installed engine steering systems shall be redundant by virtue of the fact that they are both mechanically and electrically independent of each other. A single device is allowed for control of multiple engines (e.g. steering wheel, joystick).

4.7 Each helm station shall give a visual indication when active. A main steering position shall be designated and meet the applicable requirements of ISO 11591, with the location included in the owner's manual.

4.8 Each helm station shall, by visible and/or audible means, alert the operator when the system enters the fail-safe mode.

4.9 The sound pressure of an audible alarm 1 metre from the command station shall be at least 75 dB(A), but not greater than 85 dB(A). Systems incorporating a mute feature shall maintain the visual alert as long as the failure persists.

If an audible-only alert system is utilized: muting of the alarm is not allowed.

4.10 Instructions for proper installation and use of the steering system shall be made available by the manufacturer.

4.11 Operational characteristics, instructions and warnings for proper use shall be described in the owner's manual and/or by on-product labelling.

4.12 With the exception of an optional temporary override for emergency situations, it shall only be possible to start propulsion equipment in neutral.

NOTE This includes any equipment that drives the propeller or water-jet drive.

4.13 The steering, shift and throttle actuators shall react/adjust input on a physical input command within 0,5 seconds.

4.14 Steering wheels shall comply with the requirements of ISO 8848.

4.15 Hydraulic systems shall comply with the requirements of ISO 10592.

4.16 Electrical components intended to be installed in petrol engine or petrol tank compartments shall be ignition-protected in accordance with ISO 8846.

4.17 A risk identification/analysis, using an established method, shall be carried out for each system design.

EXAMPLES Failure modes and effects analysis (FMEA), fault-tree analysis (FTA).

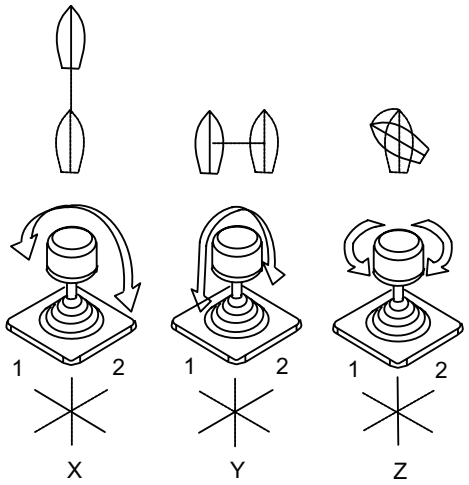
Risk identification and functional safety may be carried out as given in the relevant part of IEC 61508.

4.18 Systems that provide both cruising- and manoeuvring modes shall provide an indication to the operator at the command station of which mode the system is in, and shall not change modes without input from the operator.

5 Control head

5.1 Control head operation is permitted for both cruising-mode and manoeuvring-mode operation.

5.2 The control head position shall return to the neutral X, Y and Z axis when the operator releases his/her grip. See Figure 1.



Key

1 port

2 aft

Figure 1 — X, Y and Z commands

5.3 For operation in the cruising mode, the control head engine throttle control need not return to a low RPM or a manufacturer-determined idle state when released.

5.4 Releasing the control head in the manoeuvring mode to neutral position shall result in:

— a disengaged transmission or water-jet bucket in the neutral position;

and

— a manufacturer-determined idle state or electric motors in the stopped state.

5.5 The craft shall move in the same direction as the control head is oriented relative to the craft.

5.6 Portable helms shall clearly indicate their orientation relative to the craft.

5.7 If the control head includes a rotation function, the control head activation, clockwise or counter-clockwise, shall result in rotating the craft in the same direction.

6 Command station transfer

Transfer of command from one station to another shall be completed at the helm station intended to be active.

7 Portable helm station controls

7.1 Portable helm station controls shall be restricted to permit use only when the manoeuvring mode is selected.

7.2 Loss of communication or malfunction of the portable helm station control shall result in disengaged transmission and idling thermal engine(s) and stopping electric engine(s). The operator shall be notified of the loss of communications and the system shall not prevent transfer to another helm station.

7.3 A warning label on the portable helm or where the device is stored or charged prior to use shall be provided to advise the operator of the following warnings through the use of text or applicable ISO graphical symbols:

— keep proper lookout;

— hold on to prevent falling, boat may move suddenly;

— read owner's manual for safe use of the system.

7.4 For a wireless device, the signal strength shall be displayed at the portable control or an audible warning signal shall alert the operator that the signal is weak and he/she is about to lose control.

7.5 A wireless device shall only be able to control the boat of origin.

7.6 A wireless portable helm control shall have an indication of its electrical-charge status. The device shall prevent activation when the charge is insufficient to maintain a connection for 15 minutes without loss of the wireless communication link.

7.7 A wireless portable helm control shall notify the operator when the device is 15 minutes from deactivation due to insufficient charge.

7.8 A wireless portable helm control shall meet the requirements of applicable radio and telecommunications legislation.

8 Dynamic-positioning system (DPS)

8.1 It shall only be possible to activate DPS systems manually.

8.2 DPS systems shall have a display at the craft main helm station for the visual DPS precision value.

8.3 The following warnings shall be conveyed to the operator upon activation of the DPS through the use of applicable ISO graphical symbols or the following text:

— boat is considered under way;

— keep proper lookout;

— stay out of water, propellers are spinning;

— hold on to prevent falling, boat may move suddenly;

— read owner's manual for safe use of the system.

8.4 Activation shall only be possible if the DPS precision value is within the manufacturer-set limits.

8.5 If the dynamic-positioning (autonomous) mode is activated and the DPS precision value is out of the manufacturer-set limits at any time, the control system shall alert the operator visually and audibly of disengagement of the DPS.

8.6 Maximum allowable envelope/radius and heading deviation shall be manufacturer-set, not adjustable by the operator.

8.7 Maximum engine speed for dynamic positioning shall be manufacturer-set, not adjustable by the operator.

8.8 Helm stations not equipped with a display screen shall be labelled with the same warnings as in 8.3.

9 Failure modes and responses

9.1 Loss of operation

9.1.1 In the event of a command station malfunction in a multiple helm station system, the system shall:

— not prevent transfer to, or operation from, other helm stations;

and

— alert the operator visually and/or audibly that the failed command station is not working.

9.1.2 In the event of loss of steering control affecting only one engine in a multi-engine installation, the system shall still be capable of steering the boat.

9.1.3 In the event of a command station failure, the operator shall be notified and the affected command station shall switch to a fail-safe mode.

NOTE System performance might be at a reduced level.

9.1.4 In the event of loss of steering control in a single-engine rudder or strut installation, emergency control of the rudder shall be possible.

9.2 Loss of computer command logic

The system shall notify the operator of a command logic loss or a malfunction in its computer command logic.

10 Test requirements

10.1 General test requirements

At least three consecutively manufactured samples of each electronic and electromechanical component, as sold, shall be environmentally and mechanically tested to verify compliance with this International Standard. For EMC tests, only one sample need be tested.

Electronic and electromechanical components that have been tested and have passed with fewer than three consecutive samples and that have been in production for a minimum of five years prior to the release of this International Standard shall be considered compliant.

10.2 Steering

10.2.1 The complete system (mechanical and electrical/electronic components) shall be designed to withstand the load tests defined in this subclause. A new system may be used for each test. For clarification purposes, a cycle is defined to be the command from an input device sufficient to cause the steering system to move the output device(s) starting from hard over to opposite hard over and back to original starting position. A malfunction of any type constitutes a failure.

10.2.2 Durability test: The output device shall travel through no less than 80 % of its range as defined by the manufacturer for 100 000 cycles at a minimum rate of 10 degrees of steering angle per second under an opposing force/torque equivalent to at least the maximum force declared by the manufacturer.

In all tests, the system shall be configured as it is intended to be used in a craft application.

For rudder or strut installations the rudder load may be calculated using the craft rudder load, as detailed in ISO 12215-8.

10.2.3 High-load test: The steering actuator shall withstand a force equal to two times the force used in 10.2.2 when tested at mid travel in opposing directions.

10.2.4 Conduct these tests at the high ambient operating temperatures in Table 1, ±2 °C, and at (120 ± 2) % of nominal voltage.

10.2.5 Conduct these tests at the low ambient operating temperatures in Table 1, ±2 °C, and at (120 ± 2) % of nominal voltage.

10.2.6 Following these tests, the steering actuator shall continue to operate without failure within the original parameters specified by the manufacturer. Failure includes loose parts, cracks, wear outside of tolerance, or impaired functioning.

10.3 Joystick

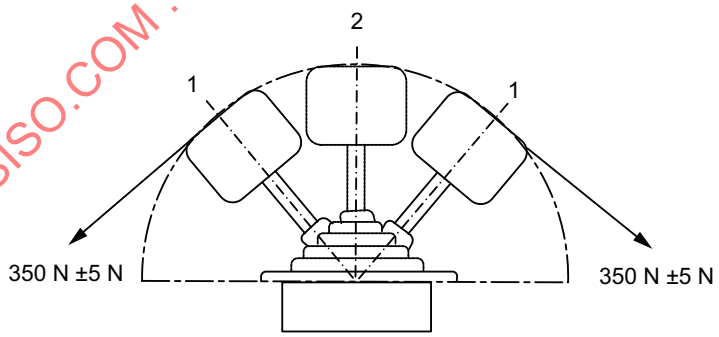
10.3.1 The joystick shall be designed to withstand a test comprising 500 000 cycles at 100 % of its stroke in each X, Y and Z direction with the minimum force applied at its end stop. A malfunction of any type, electrical or mechanical, constitutes a failure.

10.3.2 When fully moved in the +X and –X direction to its end-stop point, the joystick shall be capable of withstanding a force of (350 ± 5) N applied tangentially to the arc of the throw. See Figure 2.

10.3.3 When fully moved in the +Y and –Y direction to its end-stop point, the joystick shall be capable of withstanding a force of (350 ± 5) N applied tangentially to the arc of the throw. See Figure 2.

10.3.4 When fully twisted in the +Z and –Z direction, the joystick shall be capable of withstanding a torque of 15 Nm. See Figure 3.

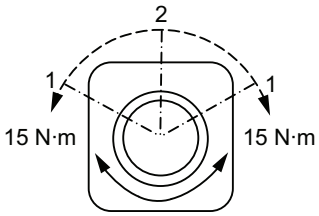
10.3.5 Following these tests, the system shall continue to operate without failure within the original parameters specified by the manufacturer. Failure includes loose parts, cracks, wear outside of tolerance, or impaired functioning.



Key

1 end stop
2 neutral

Figure 2 — Extreme-travel test, X and Y movements



Key

1 end stop

2 neutral

Figure 3 — Extreme travel test, Z rotation

10.4 Control lever, single or combined, shift and throttle

10.4.1 The system shall be designed to withstand the load tests defined in this subclause. A new system may be used for each test. For clarification purposes, a cycle is defined to be the command from an input device sufficient to cause the propulsion control system to move the output device(s) as follows:

— neutral/idle to ahead/idle (full stroke of the shift output device to ahead);

— ahead/idle to ahead/full RPM (full stroke of the throttle output device);

— ahead/full RPM to ahead/idle;

— ahead/idle to neutral/idle;

— neutral/idle to astern/idle (full stroke of the shift output device to astern);

— astern/idle to astern/full RPM (full stroke of the throttle output device);

— astern/full RPM to astern/idle;

— astern/idle to neutral/idle.

10.4.2 The system shall withstand a 75 000 cycle load test when subjected to the loads defined below.

The shift output device shall be subjected to a load of a minimum of 67 N, from neutral to near full stroke, with an over-stroke load of a minimum of 178 N applied to the shift device within the last 20 % of the shift stroke, i.e. the shift load will change from a minimum of 67 N at 80 % of the full shift stroke to a minimum of 178 N at full stroke. The load can either ramp up to a minimum of 178 N or be applied as a step function. A load increasing from 22 N at idle to a minimum of 111 N at full stroke shall be applied to the throttle output device.

10.4.3 Conduct this test at the high ambient operating temperatures in Table 1, ±2 °C, and at (120 ± 2) % of nominal voltage.

10.4.4 Conduct this test at the low ambient operating temperatures in Table 1, ±2 °C, and at (120 ± 2) % of nominal voltage.

10.4.5 In all tests, the system shall be configured as it is intended to be used in a boat application. The minimum cycle rate shall be 6 cycles per minute.

10.4.6 Following these tests, the system shall continue to operate without failure within the original parameters specified by the manufacturer. Failure includes loose parts, cracks, wear outside of tolerance or impaired function.

10.5 Environmental-test requirements

10.5.1 General

Components shall be tested at a temperature based on their intended installation in accordance with Table 1. An insulation resistance test shall be carried out before and after each damp-heat test, low-temperature test and salt mist test.

Table 1 — Environmental tests for different areas of the craft

Test	Temperatures (±2 °C)			
	Interior	Engine compartment	Damp	Wet
Salt mist		X	X	X
Vibration test	X	X	X	X
Damp heat — Cyclic	30 °C	55 °C	55 °C	55 °C
Damp heat — Steady state	30 °C	50 °C	50 °C	50 °C
High-temperature storage	85 °C	85 °C	85 °C	85 °C
High-temperature operation	70 °C	70 °C	70 °C	70 °C
Low-temperature test — Operation	–15 °C	–15 °C	–25 °C	–25 °C
Low-temperature test — Storage	–40 °C	–40 °C	–40 °C	–40 °C
Ingress protection (IP) rating	54	55	56	66

10.5.2 Salt mist tests

10.5.2.1 The salt solution shall be prepared by dissolving the compounds listed in Table 2 in one litre of distilled water. The quantities of the salts in the solution shall be within ±10 % of those shown in Table 2. The test may be carried out as described in IEC 60068-2-52.

Table 2 — Salt mist solution

Sodium chloride	NaCl	26,5 grams
Magnesium chloride	$MgCl_2$	2,4 grams
Magnesium sulfate	$MgSO_4$	3,3 grams
Calcium chloride	$CaCl_2$	1,1 grams
Potassium chloride	KCl	0,73 grams
Sodium bicarbonate	$NaHCO_3$	0,20 grams
Sodium bromide	NaBr	0,28 grams

10.5.2.2 The test chamber parameters shall be as follows:

a) salt solution shall be sprayed into the atmosphere surrounding the EUT in the chamber in the form of a fine mist at approximately one per cent of the volume of the chamber per hour;

b) to avoid contamination, salt solution dripping from the walls and ceiling of the test chamber and from the EUT shall not be recycled for re-spraying.

10.5.2.3 Salt mist — Cyclic: The cyclic test shall be carried out as follows:

a) The spraying shall continue for 2 hours, after which the EUT is to be maintained as follows:

   1) temperature: 35 °C ± 2 °C;

2) relative humidity: 90 % to 95 %;

3) duration: 7 days;

4) this procedure shall be repeated four times in succession, following which the test chamber temperature and humidity shall be reduced to ambient conditions.

b) On completion of salt mist tests, the complete system shall be subjected to one cycle of performance testing without delay, as described in 10.2 or 10.4, as applicable, to ensure the system functions without failure, or that any impaired function is within the original parameters specified by the manufacturer. The EUT shall be examined to ensure that any deterioration or corrosion is superficial in nature.

10.5.2.4 Salt mist — Continuous: The continuous test shall be carried out as follows:

a) The spraying shall continue for 300 hours.

b) On completion of salt mist tests, the complete system shall be subjected to one cycle of performance testing without delay, as described in 10.2 or 10.4, as applicable, to ensure the system functions without failure, or that any impaired function is within the original parameters specified by the manufacturer. The EUT shall be examined to ensure that any deterioration or corrosion is superficial in nature.

10.5.3 Damp heat — Cyclic

The test shall be carried out in accordance with ISO 16750-4, with the following deviations:

a) the number of cycles shall be four;

b) on completion of the damp-heat test, the system shall be subjected to one cycle of performance testing without delay, as described in 10.2 or 10.4, as applicable, to ensure the system functions without failure, or that any impaired function is within the original parameters specified by the manufacturer.

10.5.4 Damp heat — Steady state

10.5.4.1 The test shall be carried out in accordance with ISO 16750-4.

10.5.4.2 On completion of the damp-heat test, the system shall be subjected to one cycle of performance testing, as described in 10.2 or 10.4, as applicable, to ensure the system functions without failure, or that any impaired function is within the original parameters specified by the manufacturer.

10.5.5 High-temperature test — Operation

10.5.5.1 Tests and performance criteria shall be in accordance with ISO 16750-4.

10.5.5.2 The test chamber shall be configured as follows:

— temperature: raised from the initial ambient temperature to the temperature indicated in Table 1;

— duration: 48 hours.

10.5.5.3 On completion of the high-temperature test, the system shall be subjected to one cycle of performance testing, as described in 10.2 or 10.4, as applicable, to ensure the system functions without failure, or that any impaired function is within the original parameters specified by the manufacturer.

10.5.6 High-temperature test — Storage

10.5.6.1 Tests and performance criteria shall be in accordance with ISO 16750-4.

10.5.6.2 On completion of the high-temperature test, the system shall be subjected to one cycle of performance testing, as described in 10.2, 10.3 or 10.4, as applicable, to ensure the system functions without failure, or that any impaired function is within the original parameters specified by the manufacturer.

10.5.7 Low-temperature test — Operation

10.5.7.1 The test shall be carried out in accordance to ISO 16750-4 and the test chamber shall be configured as follows:

— temperature: lowered from the initial ambient temperature to the temperature indicated in Table 1 and maintained within ±2 °C;

— duration: 16 hours.

10.5.7.2 On completion of the low-temperature test, the system shall be subjected to one cycle of performance testing, as described in 10.2 or 10.4, as applicable, to ensure the system functions without failure, or that any impaired function is within the original parameters specified by the manufacturer.

10.5.8 Low-temperature test — Storage

10.5.8.1 The test procedure shall be carried out in accordance to ISO 16750-4 and the test chamber parameters shall be as follows:

— temperature: lowered from the initial ambient temperature to the temperature indicated in Table 1 and maintained within ±2 °C;

— duration: 72 hours.

10.5.8.2 On completion of the low-temperature test, the system shall be subjected to one cycle of performance testing, as described in 10.2 or 10.4, as applicable, to ensure the system functions without failure, or that any impaired function is within the original parameters specified by the manufacturer.

10.6 Vibration tests and requirements

10.6.1 Equipment mounted on engines, reverse gears or drives shall be tested in accordance with ISO 16750-3:2007, Subclause 4.1.2.6.

The same test profile shall be used for components mounted on reverse gears or drives not rigidly attached to the engine since the propeller-induced vibrations are considered to have a relatively high contribution in comparison with engine-induced vibrations.

The EUT shall meet, as a minimum, performance criterion A as described in 10.10.2.

10.6.2 Equipment installed in locations not covered in 10.6.1 shall be tested to a) or b) below. The EUT shall meet, as a minimum, performance criterion A as described in 10.10.2.

The same system shall be used to complete all testing in the present subclause. A system shall be subjected to one cycle as described in 10.2.1 to ensure that the system functions prior to the test.

a) Random vibration — The system shall be subjected to a random vibration, at 0,028 4 g^2/Hz, from 20 Hz to 2 000 Hz, applied along the three mutually perpendicular axes. The test duration shall be eight hours for each axis.

   On completion of the random-vibration test, the system shall be subjected to one cycle, as described in 10.2 or 10.4, as applicable, to ensure the system functions without failure, or that any impaired function is within the original parameters specified by the manufacturer.

b) Resonant vibration — In order to identify the major resonant frequencies, major sub-assemblies shall be subjected to a swept sine vibration along the three mutually perpendicular axes from 20 Hz to 2 000 Hz at 1g zero-peak amplitude with a sweep rate of one octave per minute. Once the resonant frequency for the individual major subassembly is known, it shall be vibrated for 10 million cycles or two hours, whichever is greater, at the maximum displacement frequency (resonant frequency) at a 1g zero-peak amplitude for each axis for off-engine-mounted units, and at four 4g's zero-peak amplitude for each axis for engine-mounted units.

On completion of the resonant vibration test, the system shall be subjected to one cycle, as described in 10.2 or 10.4, as applicable, to ensure the system functions without failure, or that any impaired function is within the original parameters specified by the manufacturer.

10.7 Shock testing

The system shall be shock-tested with an acceleration of 500 m/s^2 and a duration of 11 ms. The number of shocks shall be 3 in each direction (18 in total). Any system malfunction shall be considered as a failure.

The test may be carried out as described in IEC 60068-2-27.

10.8 Free fall

All components of the system (control unit, electrical actuators, transmitters, etc.) shall withstand a free-fall test from a height of at least 1 m with impact on a concrete floor. By the use of three samples, all six directions shall be tested (see Figure 4). Any system malfunction shall be considered as a failure.

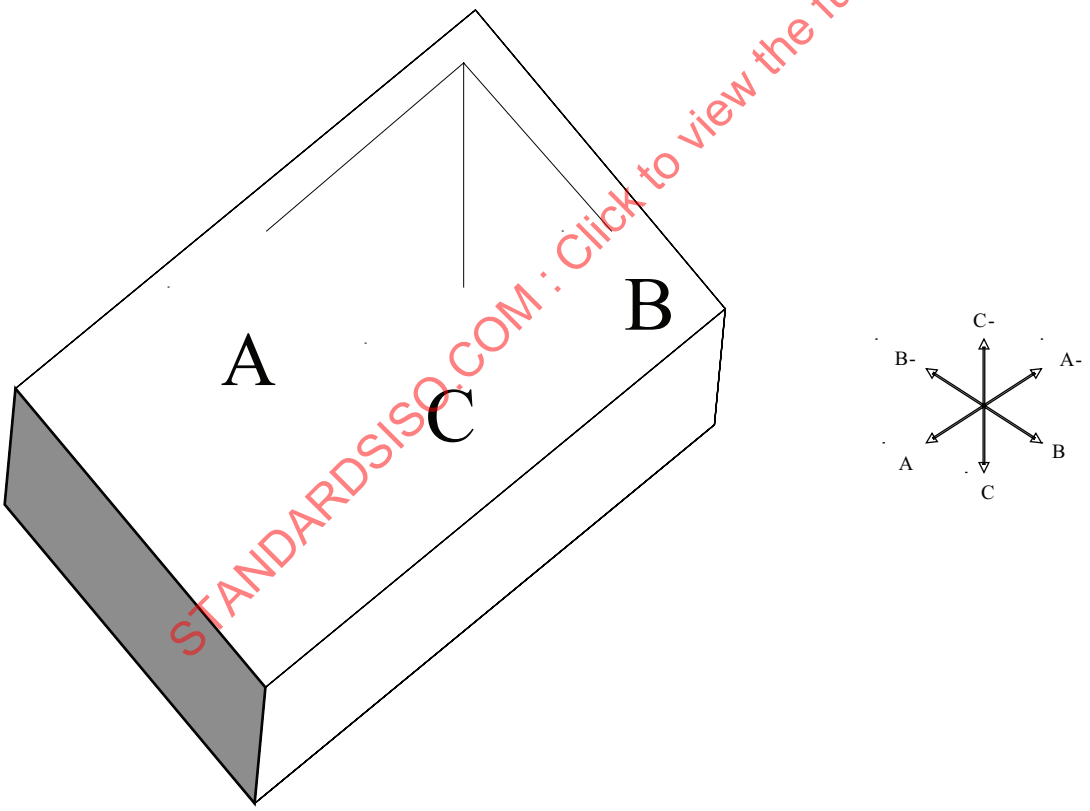


Figure 4 — Principal description of free-fall directions

10.9 Resistance to UV

If required, resistance to solar radiation shall be ensured by the choice of a suitable material.

10.10 Electromagnetic compatibility (EMC)

The boat builder shall be aware of EMC and the electrical interaction of all the components used on the craft.

10.10.1 Electromagnetic interference tests

Electronic equipment shall be subjected to the following electromagnetic interference tests for:

— immunity to conducted low-frequency interference, see 10.10.3;

— immunity to conducted high-frequency interference, see 10.10.4;

— immunity to radiated radio-frequency fields, see 10.10.5;

— immunity to fast, low-energy transients (bursts) (on power, control and signal lines), see 10.10.6;

— immunity to slow high-energy transients (surges), see 10.10.7;

— immunity to electrostatic discharge (ESD), see 10.10.8;

— immunity to power supply variation, see 10.10.9;

— immunity to radiated emissions, see 10.10.10;

— immunity to conducted emissions, see 10.10.11.

10.10.2 EMC performance criteria

Test results shall be evaluated in accordance with one of the performance criteria described below, as stated under each specific test.

— **Performance criterion A** (for continuous phenomena): The EUT shall continue to operate as intended during and after the test. No degradation of performance or loss of function, as defined in the technical specification published by the manufacturer, is allowed.

— **Performance criterion B** (for transient phenomena): The EUT shall continue to operate as intended after the tests. No degradation of performance or loss of function, as defined in the technical specification published by the manufacturer, is allowed. During the test, degradation or loss of function or performance which is self-recoverable is, however, allowed but no change of actual operating state or stored data is allowed.

10.10.3 Immunity to conducted low-frequency interference

10.10.3.1 Tests shall be carried out in accordance with IEC 60533.

10.10.3.2 The EUT shall meet, as a minimum, performance criterion A as described in 10.10.2.

10.10.4 Immunity to conducted high-frequency interference

10.10.4.1 The test shall be carried out as described in IEC 60533, applied to:

— AC/DC power lines;

— signal/control lines;

— I/O ports.

10.10.4.2 The EUT shall meet, as a minimum, performance criterion A as described in 10.10.2.