IEC TR 62131-8

Edition 1.0 2022-07

# TECHNICAL REPORT

colour inside

## Environmental conditions – Vibration and shock of electrotechnical equipment – Part 8: Transportation by ship



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# ENVIRONMENTAL CONDITIONS – VIBRATION AND SHOCK OF ELECTROTECHNICAL EQUIPMENT –

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The text of this Technical Report is based on the following documents:

| Draft | Report on voting |
|---|---|
| 104/912/DTR | 104/921A/RVDTR |

Full information on the voting for its approval can be found in the report on voting indicated in the above table.

The language used for the development of this Technical Report is English.

This document was drafted in accordance with ISO/IEC Directives, Part 2, and developed in accordance with ISO/IEC Directives, Part 1 and ISO/IEC Directives, IEC Supplement, available at www.iec.ch/members_experts/refdocs. The main document types developed by IEC are described in greater detail at www.iec.ch/standardsdev/publications.

A list of all parts in the IEC 62131 series, published under the general title *Environmental conditions – Vibration and shock of electrotechnical equipment,* can be found on the IEC website.

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# ENVIRONMENTAL CONDITIONS – VIBRATION AND SHOCK OF ELECTROTECHNICAL EQUIPMENT –

## Part 8: Transportation by ship

## 1 Scope

This part of IEC 62131 reviews available dynamic data relating to the transportation of electrotechnical equipment by marine craft such as ships and boats either at sea or during riverine use. In this instance, there is a clear similarity between dynamic data relating to the transportation of electrotechnical equipment and that of electrotechnical equipment installed on maritime platforms.

The intent is that from all the available data, an environmental description will be generated and compared to that set out in the IEC 60721 series [1][1].

For each of the sources identified, the quality of the data is reviewed and checked for self-consistency. The process used to undertake this check of data quality and that used to intrinsically categorize the various data sources is set out in IEC TR 62131-1 [2].



This document primarily addresses data extracted from several different sources for which reasonable confidence exists in their quality and validity. This document also reviews some data for which the quality and validity cannot realistically be verified. These data are included to facilitate validation of information from other sources. This document clearly indicates when utilizing information in this latter category.



The aim of this document is to review information from a number of different data gathering exercises. The quantity and quality of information in these exercises is expected to vary considerably.

Not all the data reviewed were made available in electronic form. To permit comparison to be made, in this assessment, a quantity of the original (non-electronic) data has been manually digitized.

## 2 Normative references

There are no normative references in this document.

## 3 Terms and definitions

No terms and definitions are listed in this document.

ISO and IEC maintain terminological databases for use in standardization at the following addresses:

- IEC Electropedia: available at http://www.electropedia.org/
- ISO Online browsing platform: available at http://www.iso.org/obp

[1] Numbers in square brackets refer to the bibliography.

# 4 Data source and quality

## 4.1 General

The first step in the process of reviewing available dynamic data, in this case relating to the transportation of electrotechnical equipment by marine craft, is to identify measurement exercises containing vibration and shock data which are likely to meet the validation criteria set out in IEC TR 62131-1. Whilst several exercises have been identified for this purpose, relatively few contain suitable vibration and shock data which can be realistically assessed against the validation criteria. There appears to be two underlying issues as to why little measured vibration data are available. The first is that the vibration levels experienced during sea transportation are generally of particularly low amplitude and consequently of insufficient concern to justify a measurement exercise. The second issue is that vibrations tend to occur for significant periods of time and vary with sea state. Consequently, presenting real measured data can be difficult and it is generally easier to present worst case conditions in terms of test severities. Essentially, most of the identified exercises would be classified as "supplementary data" according to the process of IEC TR 62131-1. Only two measurement exercises have been identified which have the potential to meet the required criteria and neither of those relate to large transport marine craft. For that purpose, this document has had to rely on evidence from the "supplementary data".

## 4.2 NAV vibration measurements

This measurement exercise [3] established the accelerations and vibrations on the floor of the forward and aft holds, of a relatively small (approximately 2 000 tonnes) transport vessel (RMAS Arrochar) on a three-day transit from Zeebrugge dockyard (Netherlands) to Glen Mallen on the west coast of Scotland. The journey was via the English Channel and the Irish Sea and occurred in March 1990. The measurements encompass all the prevailing conditions arising during the journey, which includes sea states from 1 to 6. This was the second of two similar measurement exercises on this class of vessel. The first exercise was on RMAS Kinterbury in July 1987 and employed a similar measurement layout in the forward and aft holds. Although measured data from the first exercise was not available for this work, the measurements and test severities derived from both exercises were compared and found to be similar. In this case, the measurement exercise and the data analysis were undertaken by separate agencies. The results of both measurement exercises were utilized to ensure the vibration experienced by an equipment were less than those to which it had been evaluated. For this purpose, a third independent agency reviewed the results.

The transport vessels used for this work, RMAS Arrochar and RMAS Kinterbury, were both naval armament vessels (NAVs) of the same class, both operated by the UK Royal Maritime Auxiliary Service (RMAS). Both vessels are now decommissioned. The vessels had two holds, both located in the centre of the ship, with the aft hold (Hold 2) the closest to the propulsion system. However, as the vessels are relatively small, both holds are in proximity to some rotating machinery, particularly the generators. Information on the overall vessel configuration, in this case for RMAS Arrochar, is shown in Figure 1.

The measurement exercise employed 24 accelerometers and three dummy loads. The latter were utilized to establish the underlying measurement noise levels at various locations in the holds. This is an issue when measuring vibration on marine craft as the vibrations can be quite low level and consequently easily influenced by contamination from electrical and mechanical noise. The exercise measured both low frequency acceleration transducers to establish payload loadings (up to 10 Hz) as well as higher frequency vibration transducers (up to 200 Hz).

The vibration measurement locations used in both measurement exercises are shown in Figure 2. Vibration measurements, on the floor of both holds, were made simultaneously. Eight piezo-electric transducers were located in the aft hold, four measuring vertical (Z) vibrations and two each for the lateral (X) and longitudinal (Y) vibrations. The transducers were configured as two triaxial assemblies and two uniaxial devices. Two triaxial transducer assemblies were located in the forward hold, each measuring in the vertical, lateral and longitudinal axis. The measurements from the two holds were recorded on separate magnetic FM tape recorders, but with measurements from one location common to both recorders. This was to enable synchronization and correlation to be undertaken for data analysis purposes.

All the spectral information presented in the available report [3] is in terms of "equivalent peak acceleration" with a frequency resolution of 0,5 Hz. Most of the measured vibration data are for conditions less than sea state 4, but with some limited data at sea state 5 to 6. Vibration severities for different sea states are presented for each hold. Noise measurements are around 0,000 1 $g^2$/Hz.

As the report only presents data in the form of "equivalent peak acceleration" it can only realistically be compared with sine-based environmental descriptions. It cannot be easily compared with power spectral density environmental descriptions without resorting to comparison of the effects of the vibration (for example using the maximum response spectrum and fatigue damage spectrum). This is an underlying issue with vibration measurements made on marine craft. Such measurements often contain sinusoidal vibrations arising from rotating machinery. Consequently, the vibration analysis methods utilized are often those appropriate for quantifying such sinusoidal vibrations. However, measurements made away from rotating machinery can be more consistent with random vibration analysis assumptions, and hence can utilize power spectral density analysis methods.

Most of the data analysis plots, included within the report, cannot be easily reproduced here. However, summary information from that data analysis is included here as Table 1 and Table 2 and Figure 3 and Figure 4. Table 1 shows the most severe acceleration levels measured for different sea states, for each vessel axis and for each hold. These measurements are limited to 10 Hz (no information on the filtering used is provided) and are intended to indicate the acceleration loading that equipment could experience during transportation. Essentially, the values are indicators of the acceleration loading any payload tie down system would need to resist. Table 2 shows the most severe vibration levels measured for different sea states, for each vessel axis and each hold. Two parameters are provided, one for the long-term root mean square of the vibrations, the other the peak-to-peak value. Table 2 is shown graphically in Figure 3.



Envelopes of the "equivalent peak acceleration" for the vertical and lateral axes and for each hold are shown in Figure 4. Also included in that figure are similar values obtained from the earlier exercise on RMAS Kinterbury. The values of "equivalent peak acceleration" shown in Figure 4 are composed of envelopes of all sea states and measurement locations in each hold and axis.

The sea state definitions for wind and sea levels, adopted for the NAV measurement exercise, were from the Douglas sea scale and information is provided in Table 3.

Although the information in the NAV vibration measurement report has some limitations, the quality of the information is reasonable and meets the required validation criteria for data quality (single data item).

### 4.3 RIB vibration measurements

This measurement exercise, undertaken in December 2005, was on a moderately sized rigid inflatable boat (RIB), used at high speed in a sea estuary and a river. The purpose of the exercise was to establish the vibration severities likely to be experienced by equipment at several cargo locations. These vibration severities were required to be compared to those experienced by the same equipment during road transportation. For commercial reasons, some measurements on certain equipment cannot be made available in this report. However, there are sufficient remaining measurements on the deck and cabin of the vessel to give a satisfactory view of the overall vibrations experienced. Given that the RIB is a relatively small craft operated at high speed, the measurements obtained from this vessel would be expected to contain some of the most extreme vibration conditions arising during maritime transportation.

The report of the measurement exercise [4] documents measurements made in both inland river conditions (referred to as "riverine") as well as during sea conditions. The riverine measurements included eight individual events made on in-shore water on the River Ore in Dorset in the UK. The sea measurements were made by following a route offshore to the entrance of Barnstaple and Bideford Bay. Most of the time was spent in high-speed traverses of the sand banks at the entrance to the bay. These sand banks produced white water conditions deemed to represent the worst-case sea state the vessel would be operated in. The speed and position of the vessel was obtained from GPS measurements. The GPS speed measurements are reproduced here as Figure 5.

As shocks were anticipated within the vibrations, all the measurements were acquired at a sample rate of 6 400 sps[2]. The vibration transducers utilized were robust integral electronic devices with a fixed sensitivity with a good voltage output which was fed directly into a solid-state data recorder. The measurement ranges for the individual transducers were set by the selection of an appropriate voltage measurement range for each recorder channel. The solid-state recorder was configured with a 1 Gb memory and it was necessary to split the riverine and sea measurements onto separate cards. However, other than that, all other measurement conditions between riverine and sea conditions remained identical. The duration of measurement of the riverine segment was approximately 23 min and for the sea segment approximately 15 min.

A total of 24 integral electronic accelerometers were used in the measurement exercise and the location of 18 of these is shown schematically in Figure 6. In this case the X axis corresponds to the vessel fore-aft (longitudinal) axis, the Y axis to athwartships (lateral) and the Z axis to the vertical axis with respect to the deck. As the environment was expected to be mainly vibration, no check was made to establish the sense of the measurement (i.e. whether positive accelerations were up going or down going). The consequences of this omission will be addressed in Clause 5, the next stage of the data validation process. The two transducers mounted on the gearbox were an attempt to measure engine speed. However, as the RIB uses water jet propulsion, these measurements were not effective for that purpose. Nevertheless, the gearbox measurements do permit the identification of engine and shaft frequencies which are also apparent at several other locations. Up to about 150 Hz these are identifiable (46 Hz, 72 Hz, 107 Hz and 140 Hz), although above that frequency so many components exist that individual identification is difficult.



The vibration analysis of the measured data was undertaken for nine separate events (eight for riverine and one for sea), these are listed in Table 4. A preliminary review of the data indicated that a few measurements were defective. This was particularly noticeable after riverine event 8, which was the longest period of sustained severe conditions. The characteristic of those measurements suggested the most likely cause was from water shorting the power supply at individual transducer connectors. This issue had been observed on a previous measurement exercise, when it was established that the transducer connector was not in-fact proof against water ingress to IPX9. The channels and events from which the data was of doubtful quality are excluded from the vibration data assessment as well as the data reproduced here.

The analysis undertaken included statistical analysis, amplitude probability densities and acceleration power spectral densities. The sample rate for the data acquisition was 6 400 sps and the frequency resolution was 0,78 Hz. This frequency resolution was considered adequate as the responses were predominantly random and, for the purpose of the work, there was no need to accurately quantify the periodic components. However, if this had been the case, a higher frequency resolution to quantify the frequency of the periodic components would have been necessary.

Summary statistical information for the vibration measurements is presented in Table 5, Table 6 and Table 7. Acceleration power spectral densities are presented for three locations in Figure 7 to Figure 14. These figures overlay the measurements from the high-speed sea

[2] Samples per second.

event as well as the eight riverine events and show the vibration severities at the forward deck, centre port deck and the rear deck. Also, for reference, an acceleration power spectral density from one of the gearbox measurements is included in Figure 15. Figure 16 and Figure 17 show the amplitude probability densities for vertical measurements at the front and rear deck, respectively, for the high-speed sea event. A time history of the acceleration measurements for the forward deck vertical axis is shown in Figure 18.

Extensive information from the RIB vibration measurement exercise was made available for the purpose of this document. Apart from the measurement issues addressed above, the quality of the information is good and meets the required validation criteria for data quality (single data item).

### 4.4 Supplementary data

The supplementary data, detailed below, comprises information arising from reputable sources, but for which the data quality could not be fully verified. In this case, the supplementary data largely comprise information of vibration test severities used by different agencies.

The French military standard GAM-EG-13 [5] includes measured vibration information from two marine craft, a naval supply tanker and a train ferry. Acceleration power spectral density information for a small number of conditions is presented. However, no information is provided on the location of the measurements or details of the marine craft. Acceleration power spectral densities for the naval supply tanker travelling at 20 kn are shown in Figure 19 and for the train ferry, again at 20 kn, in Figure 20. It is clear from the figures that the vibrations contain several periodic components and it is possible that the amplitudes shown do not necessarily accurately quantify the periodic components (this is because of the use of power spectral density to describe them).



The US defence equipment test standard MIL STD 810 [6] contains two test severities for shipborne equipment. One of these is a simple random vibration test severity (shown in Figure 21) and the other is a sinusoidal test severity (shown in Figure 22). For equipment installed on ships, both severities are required to be applied. However, for transportation of equipment, only the random vibration test severity is required.

The UK environmental test standard for defence equipment DEF STAN 00-035 [7] contains vibration test severities for equipment transported by sea as well as for equipment installed on ships. The test for transportation of equipment by sea is a simple random vibration test severity (shown in Figure 23). Several sinusoidal tests are provided for equipment installed in ships. These depend upon the size of the ship and location of the equipment. For larger ships the severities are shown in Figure 24. For smaller ships (a naval minesweeper and smaller) the severities are shown in Figure 25 and Figure 26. In this case Figure 25 relates to aft locations (close to the propulsion machinery) and Figure 26 to other locations. Broadly, the most severe test severities are for smaller ships and at (aft) locations close to the propulsion machinery.

The UK defence standard DEF STAN 00-035 [7] also contains a small amount of information related to equipment installed in the aft region of a naval frigate (again near the propulsion machinery). The measurement exercise from which this information is extracted is not disclosed nor is the specific location of the measurements. Nevertheless, it does provide some useful insight into ship vibrations. Figure 27 shows an example acceleration power spectral density which clearly shows the periodic components from the ships propulsion system as well as the harmonics of those components. Figure 28 and Figure 29 show the overall root mean square (RMS) vibration arising from different engine power demands and for different ship manoeuvre conditions, respectively.

The SRETS study [8] was undertaken during 1998 and reviewed both measured data sources and test severities for a variety of methods of transportation. For sea transportation it quotes four sources of information viz. EXACT DK 1–237:1983, MIL STD 810, DEF STAN 00-035 and GAM-EG-13. Of these only the first has not already been considered. Unfortunately, it has not been possible to confirm the existence of EXACT DK 1–237:1983. Nevertheless, the information set out in the SRETS study indicates a composite test severity made up from engine room measurements. The composite severity is shown in Figure 30. The severity is made up from measurements on a ferry (approximately 11 000 tonnes), a small bulk carrier (approximately 7 000 tonnes), a 20 m catamaran and a large bulk carrier (approximately 64 000 tonnes). The SRETS study is referenced in ASTM D4728-17 which is a random vibration test for shipping containers. Except for the SRETS reference no severities specifically for sea transport are either quoted or referenced in this ASTM.

The MIL STD 810 random vibration severity appears to arise from a measurement exercise, undertaken in the early 1970s, by J.T. Foley [9] at the US Sandia National Laboratories. Unfortunately, the analysis process used by Foley throughout his work is unique and does not lend itself to direct comparison with the information presented in this document.

Several documents have been identified which provide essentially identical, generic severities for ship design purposes. The document specially considered is Guidance Notes on Ship Vibration by the American Bureau of Shipping [10], published in 2006. Essentially two vibration severities are provided. The higher severity is associated with ship structure in the engine and equipment room. The second severity is associated with the ship structure in the remainder of the vessel. These severities are shown in Figure 31. However, there is no indication as to the source of these severities. Moreover, there is a caveat associated with the severities, relating to crew and passenger compartments. For those locations, the vibration criteria of ISO 20283-5:2016 [11] may be applicable. ISO 20283-5 specifies the vibration severities which are likely to provoke adverse criticism from crew and passengers. Whilst not entirely relevant to the purpose of this document, these severities, shown in Figure 32, provide a useful benchmark.



The IEC 60092 series are vertical product standards for electrical installations within ships. Of specific relevance here is IEC 60092-101:2018 [12] which sets out the general environmental design requirements for electrical installations. The environmental design requirements, especially those quoted within informative Annex A of IEC 60092-101:2018, are based upon those in IEC 60721-3-6:1987 [13] and adopts the same categories (6M2, 6M3 and 6M4). However, some additional values are quoted within the main body of the document which are intended for specific types of equipment, notably accumulators as well as control and instrumentation equipment. The primary mechanical environments are related to static and dynamic angular motions (addressed in 7.1) as well as vibrations and shock. The vibrations are all specified as sinusoidal and the shocks as shock response spectrum. The relationship (as specified by IEC 60092-101) between the IEC 60721-3-6:1987 mechanical categories and locations within vessels which are in excess of 500 tonnes is:

Category 6M2 Equipment in general locations including bow sections and on vessels passing through ice.

Category 6M3 Equipment in stern sections including steering gear rooms for vessels up to 10 000 tonnes as well as on masts and loading systems, for example on container guides and cranes.

Category 6M4 Equipment on reciprocating machinery.

IEC 60945 [14] provides the test requirements for maritime navigation and radio communication equipment. It groups the environmental test requirements into four types of equipment (portable, protected, exposed and submerged). The environmental tests include dry heat, damp heat, low temperature, thermal shock, drop onto a hard surface, drop into water, vibration, rain and spray, water immersion, solar radiation, oil resistance and corrosion (salt spray). The vibration test applies to all types of equipment and the procedure used is based upon that of IEC 60068-2-6 [15]. The vibration test is a sine sweep resonance search followed by a sine dwell test at all resonant frequencies identified by the sweep. The amplitudes (shown in Figure 33) are 2 Hz to 13,2 Hz at ±1 mm and 13,2 Hz to 100 Hz at 7 $ms^{-2}$. The sine dwell is 2 h at each resonance otherwise 2 h at 30 Hz. The tests are applied equally in all three axes. The drop tests apply to portable equipment only, and are six drops of 1 m onto a hard surface and three drops of 20 m onto water.

Although not strictly relevant to the purpose of this document, it is worth noting that standard ISO 20283-2:2008 [16] sets out guidance on making vibration measurements on ships. The guidance relates to conditions and manoeuvres, measurement positions, signal acquisition processing and storage as well as the content of the test report. It also provides examples of the presentation of applicable global vibration measurements. However, it provides no specific data. ISO 20283-4:2012 [17] provides similar guidance on making vibration measurements on a ship's propulsion machinery. It also provides guidance on the vibration measurement of specific types of machinery but provides no specific data.

A Swedish measurement exercise [18], undertaken in 1985, made vibration measurements on cargo during winter sea transportation, in the north Atlantic. Despite its age the exercise was competently undertaken and assessed for the effects of location, weather and cargo securing equipment. However, the full report is only available in the Swedish language and the measured data could not be readily utilized for comparison, within this document.

# 5 Intra data source comparison

## 5.1 General

The purpose of the discussion addressed in this Clause is to review each data source for self-consistency. This is part of the verification process as described in IEC TR 62131-1.

## 5.2 NAV vibration measurements



The NAV vibration measurement work presented in this document was essentially a follow-on to a similar exercise undertaken three years previously. The two exercises used different vessels, but of the same class, and made measurement in similar locations. Part of the work on the measurements from the second exercise was to compare the results with that of the first. This work indicated that the two sets of measurements produced quite similar results.

The work does provide a useful indication of how vibration levels increase with the sea state. However, it should be observed that the NAV is only a modestly sized vessel (2 000 tonnes) and will consequently be more susceptible to higher sea states, than would larger vessels. Also, when considering the observed variations with sea state, it should be remembered that whilst the different sea states have a quantitative definition, estimating a sea state (from the bridge of a ship) is still largely subjective and relies upon the experience of the observer. Also, high sea states rarely remain consistent over extended periods. Hence, some of the sea states are specified in a band.

The worst case RMS vibration severities are around 1,5 $ms^{-2}$ in the vessel vertical axis, 0,8 $ms^{-2}$ in the fore/aft axis and 0,1 $ms^{-2}$ in the lateral axis. The vertical axis measurements indicate a distinct trend of increasing amplitude with sea state. There is also trend in the fore/aft axis, but the maximum values occur at around sea state 4 and decrease subsequently (possibly due to decreased forward speed of the vessel). There is only a marginal increase in amplitude, with sea state in the lateral axis. The peak-to-peak vibrations follow a broadly similar trend, with sea state, as those observed when considering RMS vibration severities.

The spectral analysis method used for this work was unconventional. However, the use of "equivalent peak" accelerations for the analysis, was intended to allow direct comparison with an existing sinusoidal vibration test severity. Although not illustrated in this document, the "equivalent peak" accelerations were also found to follow similar trends with increasing sea state as discussed above. The spectral analysis did not show any predominant frequencies or amplitudes. Indeed, the responses are quite consistent across the frequency range from 3 Hz to 200 Hz. Although not particularly visible on the digitized plots included in this document, the original hard copy plots indicate the presence of several periodic components (see Figure 4), which are consistent across a range of locations, but nothing of significant amplitude.