PD IEC/TR 62131-5:2015

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Environmental conditions — Vibration and shock of electrotechnical equipment

Part 5: Equipment during storage and handling

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TECHNICAL REPORT

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Environmental conditions – Vibration and shock of electrotechnical equipment – Part 5: Equipment during storage and handling

INTERNATIONAL
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CONTENTS

FOREWORD 5
1 Scope 7
2 Normative references 7
3 Data source and quality 8
3.1 Container handling measurements by Hoppe and Gerock 8
3.2 Intermodal container handling by Association of American Railroads 9
3.3 Intermodal container handling at Swedish container terminal 9
3.4 Handling of air cargo pallet at Stockholm and New York airports 10
3.5 Forklift handling 11
3.6 Movement of unsuspended trolleys 11
3.7 Supplementary data 12
4 Intra data source comparison 12
4.1 General 12
4.2 Container handling measurements by Hoppe and Gerock 13
4.3 Intermodal container handling by Association of American Railroads 13
4.4 Intermodal container handling at Swedish container terminal 14
4.5 Handling of air cargo pallet at Stockholm and New York airports 14
4.6 Forklift handling 15
4.7 Movement of unsuspended trolleys 16
5 Inter data source comparison 16
6 Environmental description 19
7 Comparison with IEC 60721 20
8 Recommendations 21
Bibliography 56

Figure 1 – Vibrations loading and unloading of container on to US rail car using overhead crane [2] 25
Figure 2 – Vibrations loading and unloading of container on to US rail car using side loader [2] 25
Figure 3 – Vibrations from handling an ISO container at a port – Axial [3] 27
Figure 4 – Vibrations from handling an ISO container at a port – Transverse [3] 27
Figure 5 – Vibrations from handling an ISO container at a port – Vertical [3] 28
Figure 6 – Amplitude probability density from handling an ISO container at a port – Vertical [3] 28
Figure 7 – Amplitude probability density from handling an ISO container at a port – Transverse [3] 29
Figure 8 – Amplitude probability density from handling an ISO container at a port – Axial [3] 29
Figure 9 – Shocks from handling an ISO container at a port – Axial [3] 30
Figure 10 – Shocks from handling an ISO container at a port – Transverse [3] 30
Figure 11 – Shocks from handling an ISO container at a port – Vertical [3] 31
Figure 12 – Air pallet vibration severities due to aircraft movement – Vertical [4] 32
Figure 13 – Air pallet vibration severities due to aircraft movements – Axial/transverse [4] 33
Figure 14 – Bandpass vibration amplitudes from four forklift trucks – Vertical [5] 33

Documents
Document Sharing Hub
Full document details: PD IEC/TR 62131-5:2015

Figure 15 – Bandpass vibration amplitudes from four forklift trucks – Lateral [5] 34
Figure 16 – Bandpass vibration amplitudes from four forklift trucks – Axial [5] 34
Figure 17 – Shock response spectra from 1 000 Kg forklift truck [5] 35
Figure 18 – Shock response spectra from 1 500 Kg forklift truck [5] 35
Figure 19 – Shock Response Spectra from 2 000 Kg Forklift Truck [5] 36
Figure 20 – Shock response spectra from 3 500 Kg forklift truck [5] 36
Figure 21 – Vibration at wheels of small trolley – Vertical [6] 37
Figure 22 – Vibration at wheels of small trolley – Lateral [6] 37
Figure 23 – Vibration at wheels of small trolley – Axial [6] 38
Figure 24 – Vibration at wheels of medium trolley – Vertical [6] 38
Figure 25 – Vibration at wheels of medium trolley – Lateral [6] 39
Figure 26 – Vibration at wheels of medium trolley – Axial [6] 39
Figure 27 – Vibration at wheels of large trolley – Vertical [6] 40
Figure 28 – Vibration at wheels of large trolley – Lateral [6] 40
Figure 29 – Vibration at wheels of large trolley – Axial [6] 41
Figure 30 – Amplitude distribution at wheels of small trolley – Vertical [6] 43
Figure 31 – Amplitude distribution at wheels of small trolley – Lateral [6] 43
Figure 32 – Amplitude distribution at wheels of small trolley – Axial [6] 44
Figure 33 – Shock response spectra at wheels of small trolley – Vertical [6] 44
Figure 34 – Shock response spectra at wheels of small trolley – Lateral [6] 45
Figure 35 – Shock response spectra at wheels of small trolley – Axial [6] 45
Figure 36 – Comparison of acceleration and derived velocity for largest impacts [1] 46
Figure 37 – Comparison of acceleration and derived drop height for largest impacts [1] 46
Figure 38 – IEC 60721-3-2– Stationary vibration random severities 47
Figure 39 – IEC 60721-4-2– Stationary vibration random severities 47
Figure 40 – IEC 60721-3-2– Shock severities 48
Figure 41 – IEC 60721-4-2– Shock severities for IEC 60068-2-29 test procedure 48
Figure 42 – IEC 60721-4-2 – Shock severities for IEC 60068-2-29 test procedure 49
Figure 43 – Comparison of Hoppe & Gerock [1] derived shocks with IEC 60721-3-2 49
Figure 44 – Comparison of unsuspended trolley [6] shocks with IEC 60721-3-2 50
Figure 45 – Comparison of US forklift [5] shocks with IEC 60721-3-2 50
Figure 46 – Comparison of Swedish port [3] shocks (dockside crane) with IEC 60721-3-2 51
Figure 47 – Comparison of Swedish port [3] shocks (mobile crane) with IEC 60721-3-2 51
Figure 48 – Comparison of Swedish port [3] shocks (straddle carrier) with IEC 60721-3-2 52
Figure 49 – Comparison of Swedish port [3] shocks (transport tug) with IEC 60721-3-2 52
Figure 50 – Comparison of Swedish air transport [4] vibrations with IEC 60721-3-2 53
Figure 51 – Comparison of unsuspended trolley [6] vibrations with IEC 60721-3-2 53
Figure 52 – Comparison of Swedish port [3] vibrations (transport tug) with IEC 60721-3-2 54
Figure 53 – Comparison of Swedish port [3] vibrations (dockside crane) with IEC 60721-3-2 54
Figure 54 – Comparison of Swedish PORT [3] vibrations (mobile crane) with IEC 60721-3-2 55

Documents
Document Sharing Hub
Full document details: PD IEC/TR 62131-5:2015

Figure 55 – Comparison of Swedish port [3] Vibrations (straddle carrier) with IEC 60721-3-2 55

Table 1 – Maximum vibration accelerations and displacements occurring during handling of ISO containers at container terminal [1] 22
Table 2 – Largest shocks occurring during handling of ISO containers by straddle carrier [1] 23
Table 3 – Largest shocks occurring during transfer of ISO containers on to rail cars [1] 23
Table 4 – Largest shocks occurring during transfer of ISO containers on to ships [1] 24
Table 5 – Largest shocks occurring during transfer of ISO containers on to US rail cars [2] 24
Table 6 – Summary of vibration r.m.s. during port movements of ISO containers [3] 26
Table 7 – Summary of peak shock severities during port movements of ISO containers [3] 26
Table 8 – Summary of shock levels from air cargo pallet ground operations [4] 31
Table 9 – Summary of peak vibration levels from air cargo pallet ground operations [4] 32
Table 10 – Summary of overall vibration severities [6] 42

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Document Sharing Hub
Full document details: PD IEC/TR 62131-5:2015

INTERNATIONAL ELECTROTECHNICAL COMMISSION

ENVIRONMENTAL CONDITIONS – VIBRATION AND SHOCK OF ELECTROTECHNICAL EQUIPMENT –

Part 5: Equipment during storage and handling

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IEC TR 62131-5, which is a technical report, has been prepared by IEC technical committee 104: Environmental conditions, classification and methods of test.

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The text of this technical report is based on the following documents:

Enquiry draft	Report on voting
104/620A/DTR	104/639/RVC

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

This publication has been drafted in accordance with the ISO/IEC Directives, Part 2.

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

The committee has decided that the contents of this publication will remain unchanged until the stability date indicated on the IEC website under "http://webstore.iec.ch" in the data related to the specific publication. At this date, the publication will be

- reconfirmed,
- withdrawn,
- replaced by a revised edition, or
- amended.

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ENVIRONMENTAL CONDITIONS – VIBRATION AND SHOCK OF ELECTROTECHNICAL EQUIPMENT –

Part 5: Equipment during storage and handling

1 Scope

IEC TR 62131-5, which is a technical report, reviews the available dynamic data relating to the handling of electrotechnical equipment. The intention is that from all the available data an environmental description will be generated and compared to that set out in the IEC 60721 series.

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.

This technical report primarily addresses data extracted from a number of different sources for which reasonable confidence exist in its quality and validity. The report 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. The report clearly indicates when utilising information in this latter category.

This technical report addresses data from a number of data gathering exercises. The quantity and quality of data in these exercises varies considerably as does the range of conditions encompassed.

Not all of 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

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 60068 (all parts), *Environmental testing*

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

IEC 60068-2-29[1], *Environmental testing – Part 2-29: Tests –Test Eb Bump*

IEC 60068-2-64, *Environmental testing – Part 2-64: Tests – Test Fh: Vibration, broadband random and guidance*

IEC 60721 (all parts), *Classification of environmental conditions*

IEC 60721-3-2:1997, *Classification of environmental conditions – Part 3: Classification of groups of environmental parameters and their severities – Section 2: Transportation*

[1] Withdrawn and now incorporated into IEC 60068-2-27.

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IEC TR 60721-4-2, *Classification of environmental conditions – Part 4-2: Guidance for the correlation and transformation of environmental condition classes of IEC 60721-3 to the environmental tests of IEC 60068 – Transportation*

IEC TR 62131-1, *Environmental conditions – Vibration and shock of electrotechnical equipment – Part 1: Process for validation of dynamic data*

IEC TR 62131-2, *Environmental conditions – Vibration and shock of electrotechnical equipment – Part 2: Equipment transported in fixed wing jet aircraft*

IEC TR 62131-3, *Environmental conditions – Vibration and shock of electrotechnical equipment – Part 3: Equipment transported in rail vehicles*

IEC TR 62131-4, *Environmental conditions – Vibration and shock of electrotechnical equipment – Part 4: Equipment transported in road vehicles*

3 Data source and quality

3.1 Container handling measurements by Hoppe and Gerock

Work by Hoppe and Gerock was under taken in the early 1970s and the resultant data are reproduced in a number of publications (see [1])[2].

Those data appear to have formed the basis for the road transportation severities in a number of national standards. Moreover, as far as can be identified, they are probably the original basis for the severities in IEC 600721-3-2. As the measured data also include a number of handling conditions, it is likely they were also considered in setting such severities. Although the measured data presented are limited, the scope of the measurements is sufficient to justify their inclusion here.

The Hoppe and Gerock work relating to handling, involved vibration and shock measurements on ISO containers at the container terminal, Hamburg/Burchardkai, during both in-yard transport and handling. The measurements included both 6 m (20 foot) and 12 m (40 foot) units when empty and loaded. Loaded 6 m and 12 m containers were also transferred onto a container train by means of a gantry crane. Dock side to ship measurements were made on loaded 6 m containers only.

Acceleration measurements were made at six locations within the containers; door end centre (in three orthogonal axes), door end right hand side (vertical only), centre of container (vertical only) and at the forward wall centre (vertical only). All six measurements were recorded simultaneously and continuously on an analogue FM recorder. The frequency range covered was 1 Hz to 1 250 Hz. All PSD analysis was undertaken using a 3 Hz frequency resolution and a record duration of 32 s.

The ISO containers used comprised steel framed structures with plywood walls with roofs reinforced with laminated fibreglass. The 6 m container was manufactured in 1969/70, it had an empty mass of 1 950 Kg and a loaded mass of 20 320 Kg. The 12 m containers were manufactured in 1970/71, had an empty mass of 3 490 Kg and a loaded mass of 30 480 Kg.

The container vibration measurements made during movement around the container terminal are summarised in Table 1. The measurements were found to contain predominant resonances associated with the suspension of the straddle or van carrier used to undertake the movements (typically at between 2 Hz to 3 Hz), the spreader used to support the container (6 Hz to 7 Hz)

2 Numbers in square brackets refer to the Bibliography.

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and of the containers themselves (at around 160 Hz, 240 Hz and 400 Hz). The largest accelerations and displacements were consistently found to occur in the vertical direction and at the centre of the container. The largest derived displacement arose from carriage of the empty 6 m container at the maximum permissible speed. For the other container conditions the maximum speed was 20 km/h to 25 km/h.

The corresponding shock measurements when the containers were handled by the straddle or van carrier are summarized in Table 2. These include peak amplitudes occurring during pick up, set down on to the ground as well as set down on to another container. Again the largest accelerations were consistently found to occur in the vertical direction and at the centre of the container. The largest shocks were noted to occur during engagement and disengagement of the spreader.

The Hoppe and Gerock work also included measurements picking up and setting down containers on to rail vehicles (summarized in Table 3) and during transfer on to ships (summarized in Table 4).

The shock measurements are all presented in terms of peak acceleration amplitude and shock duration. No time histories are presented so the method used for the derivation of shock duration cannot be verified. Only one Shock Response Spectra (SRS) for handling is presented and its origins are unclear.

Although the information in this report is limited the quality of the information is reasonable and meets the required validation criteria for data quality (single data item).

3.2 Intermodal container handling by Association of American Railroads

This relatively recent (1991) work from the Association of American Railroads (see [2]) concerns the measurement and analysis of vibration and shock conditions experienced by standard ISO containers when transported by both rail and road. The objective was primarily to establish the relationship between the vibration and shock conditions experienced during rail and road movements. However, the work also includes shock and vibration measurements that occurred during handling. The data source relates almost entirely to ISO containers on the US and Canadian rail system.

The report indicates that the handling measurements utilized a self contained recorder. The recorder was programmed to record data in 7,7 sblocks of data when a threshold of 0,1 g was exceeded for more than 3,9 ms. These recorder settings were selected in an attempt to collect data virtuously continuously. The sample rate was 256 samples per second (sps) filtered at 30 Hz with a Butterworth low pass filter. The pre-programmable data recorders housed three orthogonal accelerometers capable of DC measurement (using piezoresistive accelerometers) in the vehicle fore/aft, lateral and vertical axes.

Measurements were made on a trailer carrying a 12 m (40 foot) ISO container, whilst it was loaded on and off rail cars. The loading and unloading adopted both overhead crane and a sideloader. The peak acceleration levels from these operations are summarized in Table 5 and the associated acceleration power spectral densities are shown in Figures 1 and 2.

The information in this report is limited to a trailer carrying 12 m (40 foot) ISO containers. It may also be specific to the US and Canadian rail systems. However, the quality of the information is good and meets the required validation criteria for data quality (single data item).

3.3 Intermodal container handling at Swedish container terminal

These very recent measurements (2007) were undertaken by Mariterm AB in conjunction with Helsingborgs container port (see [3]). The measurements relate to the handling of a 12 m (40 foot) empty container at the Helsingborgs container port.

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The measurements were acquired using a data acquisition DT9816 recorder; this allowed measurement of 6 channels (2 × three orthogonal axes) of acceleration measurements. The digital recorder comprised a 12 bit ADC sampling at 1 500 sps. Four channels of measurements were low pass filtered at 370 Hz (one tri-axial and the fore/aft channel of the other) and two channels at 500 Hz. The accelerometers were positioned along the centre line of the container, on the floor and around 6 m apart. Although, the measurement axis of each channel is known, the specific identification of the tri-axial accelerometer is unclear. For this reason, the measurements are designated as from transducer groups 1 and 2.

The recorder measurement range was set to 10 g, which in comparison to other exercises, is somewhat low. Moreover, a few of the shocks, specifically in the vertical axis, appear to exceed this measurement range.

Measurements were made during handling of the container by a dockside container crane, movement by a container tug, handling by a container crane and handling by a straddle carrier. For each condition several separate measurement runs were made. Some attempt appears to have been made at making the measurements during different severities of handling conditions.

The report [3] supplies both sample time histories (albeit encompassing the entire record, typically 10 min to 20 min) and summary peak acceleration data along with approximate duration of the shock event. However, in addition to the report, the electronic measured data were also made available.

From the electronic data, summary information on the vibration severities are assembled in Table 6 and summary information of the highest shocks measured is presented in Table 7. Envelopes of the vibration acceleration power spectral densities, from each of the four handling conditions and for each axis, are presented in Figures 3 to 5. Amplitude probability densities, again for each of the four handling conditions and for each axis, are presented in Figures 6 to 8. Shock response spectra are presented in Figures 9 to 11.

Although the information in the hardcopy report is limited, the quality of the electronic information is good and meets the required validation criteria for data quality (single data item).

3.4 Handling of air cargo pallet at Stockholm and New York airports

The Swedish Packaging Research Institute reported a field study of loadings on an air cargo pallet in 1988 (see [4]). The measurements were made both on board a Boeing 747 Combi (freight and passenger) aircraft and also during cargo handling operations at both Stockholm airport (Arlanda) and New York (John F. Kennedy Airport). Shock and vibration acting on the cargo during handling were measured and analysed.

A tri-axial accelerometer was mounted on the pallet with double-sided tape and was placed approximately midway along the length of the pallet, about 0,5 m from the pallet edge. A fourth, separate, vertical accelerometer was mounted near the end of the pallet, approximately 0,5 m from the corner. The transducers were not mounted on the cargo in an attempt to establish acceleration measurements sensibly independent of cargo type. Nevertheless, the pallet loads chosen were 'typical'. During the outward stages (stages 1 to 3) the weight of the test pallet was 1 470 kg and during the return journey (stages 4 and 5) the weight was 2 550 kg. The measurement encompassed five stages:

– Stage 1 Arlanda terminal to aircraft, pallet weight 1 470 kg;
– Stage 2 Arlanda movement at aircraft, pallet weight 1 470 kg;
– Stage 3 JFK aircraft to terminal, pallet weight 1 470 kg;
– Stage 4 JFK terminal to aircraft, pallet weight 2 550 kg;
– Stage 5 JFK loading on aircraft, pallet weight 2 550 kg.

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The field data recorded during the trip have been computer analysed in the time and frequency domains. The frequency domain analysis was carried out using both conventional spectral analysis and autoregressive modelling techniques. The sampling frequency chosen was 100 Hz and the signal was low-pass filtered at 31,5 Hz. The number of records, each spanning 256 samples, depended on the conditions under investigation. However, this was limited to 350 records, i.e. a sampling time of no more than 15 min. The window mostly used for the frequency analysis was the Blackman window. For the analysis using autoregressive modelling for the spectral estimation, the Hamming window was used.

A summary of the recorded extreme handling shock values and r.m.s. values are given in Table 8. A summary of the corresponding vibration data is shown in Table 9. The vibration data comprise acceleration levels (g) exceeded for 1 % of the time of the trial. Vibration spectra for each stage are shown in Figures 12 and 13 for the vertical and transverse axes respectively.

3.5 Forklift handling

This 1975 measurement exercise (see [5]) was undertaken by M.B. Gens at the Sandia Laboratories in the US adopted a common payload and four different size forklift trucks. Although a little old these measurements are the basis for conditions in several standards.

The measurement exercise addressed the transient conditions arising from traversing a test track made up of paved and unpaved areas. The paved areas included asphalt streets with manhole covers and metal utility covers as well as concrete aprons and driveways. The paved surfaces included both new and smooth surfaces as well as old and deteriorated surfaces. The unpaved areas were not intended as a driving surface and included steps of up to 25 mm. Experienced drivers were used, each instructed to travel at highest speed possible consistent with retaining the payload. In general, speeds were reported to be less than 10 mph (16 km/h) and mostly below 5 mph (8 km/h).

The measurements were made both on a pallet carrying a payload and the payload itself. The report indicates the payload as having a mass of 1 000 lb (500 Kg). The four forklift trucks were characterized as

– 1 000 kg (2 000 lb) capacity, electric powered and solid tyres;
– 1 500 kg (3 000 lb) capacity, petrol powered and pneumatic tyres;
– 2 000 kg (4 000 lb) capacity, petrol powered and pneumatic tyres;
– 3 500 kg (7 000 lb) capacity, petrol powered and pneumatic tyres.

The measurements were made using two groups of orthogonally orientated transducers; one group selected and set to measure accelerations up to 50 g peak-to-peak, the other to 10 g peak-to-peak. Tri-axial measurements from both groups were made at two locations; one close to the input from the forks and the other on the skin of the payload. All measurements were recorded on an FM tape recorder.

The 5 Hz band pass analysis of the data elicited the conclusion that no steady state continuous randomly distributed excitation was present in the forklift environment. Discrete excitations, on the other hand were prevalent. A total of 49 vibration spectra (from all four forklift trucks) were combined to allow plots of mean, mean plus three standard deviations as well an envelope of maximum response. The responses for the pallet measurements (effectively the excitations applied to the payload) are shown in Figures 14 to 16 for the vertical, lateral and axial axes respectively. The envelopes of largest shock response spectra for each of the four forklift trucks are shown in Figures 17 to 20.

3.6 Movement of unsuspended trolleys

This very recent (2009) measurement exercise (see [6]) was undertaken, by Drager Medical, to determine the vibration and shock conditions arising from the movement of medical trolleys over flooring typically occurring within modern building and outside in car park type surfaces. The three trolleys have small, unsuspended castor type wheels which are common to many

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items of modern electro-technical equipment. They are also typical of handling trolleys commonly used to move small packages on and off trucks and around warehouses. All the movement occurred at walking speed.

The measurements were made on three different medical devices as set out below. In each case the tri-axial acceleration vibration measurement were made on the support system, just above the wheels:

– small trolley – A small medical ventilator, mass 22,5 kg, castors 100 mm diameter, castor surface PA6 of hardness Shore A 80;
– medium trolley – Anaesthetic workstation, mass 147 kg, castors 125 mm diameter, castor surface polyurethane of hardness Shore D 40;
– large trolley – Intensive care ventilator, mass 54 kg, castors 125 mm diameter, castor surface polyurethane of hardness Shore D 40.

The intended velocity of the movements was 0,5 m/s although the real velocity appears to have varied between 0,5 m/s and 0,7 m/s. Movement was in the X (axial) axis with the Z axis vertical. The typical 5 surface types traversed were

- composite stone,
- granite plates 70 cm × 70 cm,
- pvc floor 60 cm × 60 cm at 0,5 m/s and 0,7 m/s,
- asphalt light grey,
- asphalt rough.

The transducers and measurement system are indicated as within calibration. The digital recorder sample rate was 8 192 sps and the remainder of the measurement chain was capable of measurements of at least 3 kHz. The recorder utilized a 16 bit ADC, an anti-aliasing filter of 3,2 kHz. The measurement record lengths varied between 1 min and 3 min although 120 s was commonly achieved. In this case the measured data and all the analysis are available digitally.

Shown in Figures 21 to 29 are the vibration severities for each of the three axes for each of the three devices. A summary of the corresponding overall acceleration root mean square values are presented in Table 10. Amplitude Probability Density (APD) values for the device which experienced the most severe conditions (the small medical ventilator) are show in Figures 30 to 32. Corresponding Shock Response Spectra (SRS) for the same device are shown in Figures 33 to 35.

3.7 Supplementary data

The data collection exercises which preceded this particular assessment attempted to supplement the data with any relevant sets of information, arising from reputable sources, but for which the data quality could not be adequately verified. Although no additional sources were identified, a SRETS study (see [7]) undertaken during 1998 reviewed the types and occurrences of damage that occur as a result of transportation and particularly that identified during handling related to transportation. Although that report (see [8]) contains no specific information on the mechanical environments occurring during handling, it does give a good review of the different types of damage a range of items may experience during handling.

4 Intra data source comparison

4.1 General

The purpose of the following subclauses is to review each data source for self consistency. The process for evaluating the vibration data takes into account the variations arising from the different methods of handling.

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4.2 Container handling measurements by Hoppe and Gerock

Although the extent of the vibration information, tabulated in the Hoppe and Gerock report, is relatively limited it does, with one exception, appear reasonably consistent. The acceleration amplitudes are quite low, possibly giving rise to concerns over measurement accuracy. The derived displacements are relatively high, for the low acceleration levels, suggesting low frequency excitations (which are confirmed in the report). With that said, the report does not make clear the method used for deriving displacements from the acceleration measurements. The concern is that high displacements can arise if this is not undertaken appropriately. The distribution of amplitudes between full and empty containers, as well as between axes, is largely as would be expected. The one value that is out of line with the remainder is the vertical measurement on empty containers. The acceleration amplitude indicated is more than double any other tabulated value and the listed peak displacement is four times greater than any other. The occurrence of this condition is explained in the report as due to high movement speeds. The indicated peak displacement is essentially the same as the largest equivalent drop height suggested from consideration of the shocks.

The tabulated handling impact acceleration amplitude values, presented in the Hoppe and Gerock report, indicate an underlying trend. That is smaller empty container generally generate the worst case conditions whilst the largest loaded containers generally result in lower impact acceleration amplitudes. This is entirely as would be expected.

The shock data quotes acceleration amplitudes as well as durations. As a consequence of the different approaches used, the validity of tabulated shock durations, without a description of how they were derived, is always questionable. A verification exercise has been undertaken, which assumes the shocks are a result of impacts between two elastic bodies. The exercise indicates that the accelerations and the derived velocities follow a realistic and consistent relationship, Figures 36 and 37 refer respectively. Only a few values fall outside the main trend but even those are only to an extent expected from measured data. The largest indicated velocity change is 0,6 m/s with the majority of impacts occurring below 0,4 m/s. The values suggest that size of container or its loaded state makes no underlying difference to the velocity. The largest equivalent drop height, derived from the velocities, is a little less than 19 mm.

The Hoppe and Gerock report supplies only a single shock response spectrum for the handling impacts and this is marked as 'typical'. Nevertheless, the shape of the shock response spectra is typical of that for short duration impacts of the type indicated by the tabulated values.

Overall, the Hoppe and Gerock data appears self-consistent, showing trends and values that are largely within expectations. The data meets the required validation criteria for quality against the intra data source comparison criteria.

4.3 Intermodal container handling by Association of American Railroads

The handling information presented by the Association of American Railroads report is quite limited and the handling measurements clearly were not the primary objective. The shock values appear reasonable consistent although, given the limited information, no useful trends can be discerned. The relationship between axes appears reasonable and as would be expected. The frequency spectra indicate quite low frequency content from both handling devices. The main concern with this data is that it is sampled at 256 sps and low pass filtered at 30 Hz which is quite low for shock measurements. This may be limiting the peak amplitudes measured. Also as no shock durations are indicated, the equivalent velocity and displacement cannot be derived.

Although the data, in the Association of American Railroads report, meets the required validation criteria for quality against the intra data source comparison criteria, it is limited in both extent and range. The Association of American Railroads report supplies shock amplitudes but not the corresponding durations. As a consequence they cannot be credibly compared with other data and have only limited usefulness in the comparison with existing environmental descriptions addressed hereinafter.

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4.4 Intermodal container handling at Swedish container terminal

The Mariterm AB measurements, made at the Helsingborgs container terminal, encompass similar handling conditions to those of the Hoppe and Gerock work. However, the Mariterm AB measurements are recent and available in electronic form. The primary concern arising from primary review of the data is that some of the peak amplitudes of the vertical shock values exceed the stated measurement range of 10 g.

The vibration r.m.s. values shown in Table 6 indicate a reasonable degree of consistency notably that the responses in the vertical axis are markedly greater than those in the transverse axis, which is in turn are greater than the axial axis. The severities of transducer group 1 are mostly greater than transducer group 2. However, this fact is not particularly useful without knowledge of the specific locations at which the groups are located.

The vibration power spectral densities shown in Figures 3 to 5, indicate that at low frequency (below 10 Hz) the movement of the straddle carrier is the most severe condition. At higher frequencies the movement of the mobile handling crane is consistently the most severe. The suspension frequency of the various handling vehicles is clearly identifiable in all axes, but is particularly significant in the vertical axis. Modal responses, apparent at 30 Hz and 55 Hz, are assumed to arise from the container.

The amplitude probability densities, shown in Figures 6 to 8, indicate a reasonably well defined Gaussian distribution in the transverse and axial axes. In these axes the amplitude distributions are contained within the measurement range and imply only modest shocks superimposed upon the vibrations. The distribution in the vertical axis is very similar to that identified for road vehicles. Specifically they contain a, low amplitude and high probability distribution, which represents the vibrations. Onto this vibration distribution is superimposed a second, higher amplitude and lower probability distribution, usually assumed to represent the shocks. This latter distribution is mostly contained within the measurement range (of 10 g) but some single occurrences are outside this range.

The shock response spectra, computed from the full measurement record, are shown in Figures 9 to 11. The shock response spectra indicate similar trends to those of the corresponding power spectral densities. Specifically, at low frequency (below 10 Hz) the movement of the straddle carrier is the most severe condition. At higher frequencies the movement of the mobile handling crane is consistently the most severe. Apart from at low frequency, identified as the vehicle suspension frequencies, the shock response spectra are credibly consistent. The shock response spectra correspond to a velocity change of up to 0,2 m/s in the axial axis, 0,5 m/s in the transverse axis and 1,0 m/s in the vertical axis. These relate to an equivalent drop heights of 2 mm, 12,5 mm and 30 mm in the axial, transverse and vertical axes, respectively.

The Mariterm AB measurements essentially meet the required validation criteria for quality against the intra data source comparison requirement. However, some concern remains that a few vertical measurements exceed the set measurement range.

4.5 Handling of air cargo pallet at Stockholm and New York airports

The Swedish Packaging Research Institute study of handling loads on an air cargo pallet were made on board a Boeing 747 Combi (freight and passenger) aircraft. This was integral with that intended to make in-flight vibration measurements and reported in IEC TR 62131-2. The verification exercise of those vibration measurements highlighted issues with the low sample rate (100 sps) and the frequency of the low pass filter (31,5 Hz). As the measurement system was identical, for the handling and in-flight vibration measurement exercises, these aspects are also of concern here. The relatively low shock and vibration amplitudes observed in these measurements are almost certainly influenced by the low sample rates.

The vibration information, presented in the form of acceleration power spectral densities (PSDs), all show signs of a reasonably significant random error. The highest spectral density amplitudes mostly occur at low frequency. However, the PSDs encompass a frequency range

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beyond that of the low pass filter. As a consequence some care needs to be taken with the information above around 25 Hz.

The tabulated shock and vibration handling measurements show a broad degree of consistency. The vertical axis produces the most severe acceleration amplitudes with the measurements at the corner of the air freight pallet more severe than the centre. The measurements made at JFK airport are more severe than Arlanda; this the report attributes to less stringent controls at JFK. This would appear to be supported by consistently more severe vibration and shock measurements at JFK. No shock duration information is supplied nor is any form of data presentation employed that would allow velocity or equivalent drop heights to be derived.

The Swedish Packaging Research Institute measurements from handling of an air cargo pallet make a useful contribution to this review of handling conditions. Nevertheless, concerns over the limited frequency range imply that the validation criteria for quality against the intra data source comparison requirement are only met with reservation.

4.6 Forklift handling

Although the US measurements on four different sized forklift trucks were made some time ago, the work was undertaken by a competent authority with significant resources. Although a little old, the shock measurements still appear within several current test standards.

The most obvious reservation with the Shock Response Spectra (SRS) envelopes is that the frequency range adopted is a little limited. Many of the SRS envelopes are still rising at the highest frequency, suggesting the frequency encompassed was insufficient. The lower frequencies indicate a fair amount of variation, which can sometimes be indicative of poor measurements. However, in this case the shock response spectra are stated to be envelopes generated from a significant number of measurements. As such the individual SRS are unlikely to represent any single event. This could explain the observed variations at the lower frequencies.

The three sets of SRS measurements from the petrol powered and pneumatic wheeled forklift trucks imply a believable trend of decreasing shock levels with increasing forklift size. Broadly speaking, the amplitude of the vertical shocks exceed those from the other two axes. Moreover, the vertical axis indicates a low frequency response (typically 3 Hz to 5 Hz) which would be expected from the pneumatic wheels. The electric solid wheeled forklift truck shows much lower SRS levels than the other three. This seems likely to be a consequence of the lower speed capability of that vehicle, especially on the rougher surfaces.

The vibration severities are in the form of band pass acceleration levels, presented in terms of statistical mean, mean plus three standard deviations and measured peak. This form of presentation was fairly typical of vibration measurements emanating from this establishment at that time. Unfortunately, when presented in this way the vibration measurements are difficult to utilize directly but are useful checks on other data. The peak value envelopes of the vibration measurements are consistently greater than the mean plus three standard deviation envelopes. Moreover, the peak value envelopes are consistently around 3 times greater than the mean envelopes. Together these imply that the vibrations are largely Gaussian, and the standard deviations of the measurements are consistently low. All of this typifies good measurements. The vertical axis measurements indicate a clear and well defined vehicle suspension/tyre mode at around 5 Hz. This is not apparent in the other two axes.

Overall, the forklift truck data appear self-consistent, showing trends and values that are largely within expectations. Both the shock and vibration data meet the required validation criteria for quality against the intra data source comparison criteria. However, the presentation of the vibration data means it is not particularly useful as a means of setting practical vibration test severities. However, the information could be useful to confirm existing information.

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4.7 Movement of unsuspended trolleys

The recent measurement from the movement of three medical trolleys was available digitally, allowing detailed information to be presented. The measurements encompass movement over five surfaces typical of the flooring within modern buildings and immediate vicinity. The measurements were typically made just above a wheel, thus allowing use for similar items of equipment.

The results from the various measurements indicate a degree of consistency. The amplitude distribution from all the measurements are fundamentally random, but with a Kurtosis greater than would be expected from a purely Gaussian distribution. The amplitude distribution measured is typical of that seen on vehicles experiencing a mix of vibration and shocks. In this case, the peak values are typically around 10 times greater than the acceleration root mean square, or around 3 times greater than would be expected from a purely Gaussian distribution. This trend is exhibited by the “rougher” surfaces for all three trolleys in all three axes. The “smoother surfaces” show an amplitude distribution closer to a Gaussian distribution.

Broadly, the frequency spectra from all three trolleys show a similar trend. However, as would be expected, the strong lower frequency modes (typically 20 Hz to 40 Hz) are different for each trolley and each axis. The power spectral densities (PSD) shows a greater medium frequency content than observed on some of the other vehicles. However, this is not entirely surprising given that the three trolleys have no intrinsic suspension system. The PSD amplitudes are seen to be more severe for the floor surfaces typically found outside a building (asphalt and composite stone). The surfaces typically found inside a building (PVC and granite tiles) are observed at around an order lower than those for external surfaces.

The consistency between axes is reasonable, although, in terms of peak and overall r.m.s. acceleration, the vertical axis is not, as would be expected, the most severe. In terms of these parameters the fore/aft axes is consistently the most severe, albeit, not by a large margin. As a consequence, some doubt arises as to whether the axes were correctly defined.

Overall, the medical trolley measurements appear to indicate self-consistent trends and values that are largely within expectations. Some slight concern exists as to whether the axes were correctly defined. Nevertheless, the data meets the required validation criteria for quality against the intra data source comparison criteria. The trolleys had small, unsuspended castor type wheels which are common to many items of modern electro-technical equipment. As such, they are also typical of handling devices commonly used to move small packages on and off trucks and around warehouses.

5 Inter data source comparison

For the most part, the data from the various sources indicated a reasonable degree of self consistency. However, it is clear some differences exist between sources, conditions encompassed and the type of information available from the individual measurement exercises.

Considering firstly the shock severities from the pick-up and set down of ISO containers, for which information from three different sources are available. Of these sources, the Hoppe and Gerock data is the oldest but also the most comprehensive. It indicates peak acceleration amplitudes up to 38 g, a value which is very much consistent with the remaining data. The peak acceleration amplitudes do vary with payload mass and container size, with the smallest empty containers giving the highest acceleration amplitudes. Shock duration information supplied indicate the largest velocity change as 0,6 m/s. The values suggest that size of container or its loaded state make little underlying difference to the velocity. The largest equivalent drop height for the velocities is a little less than 19 mm.

The Mariterm AB measurements, made at the Helsingborgs container port, also addressed the pickup and set down of ISO containers, but are far more recent measurements. Although a few measurements may be limited in peak acceleration amplitudes to 10 g, the general distribution

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