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TECHNICAL REPORT

colour inside

Environmental conditions – Vibration and shock of electrotechnical equipment – Part 3: Equipment transported in rail vehicles

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Environmental conditions – Vibration and shock of electrotechnical equipment – Part 3: Equipment transported in rail vehicles

INTERNATIONAL
ELECTROTECHNICAL
COMMISSION

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INTERNATIONAL ELECTROTECHNICAL COMMISSION

ENVIRONMENTAL CONDITIONS – VIBRATION AND SHOCK OF ELECTROTECHNICAL EQUIPMENT –

Part 3: Equipment transported in rail vehicles

FOREWORD

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IEC/TR 62131-3, which is a technical report, has been prepared by IEC technical committee 104: Environmental conditions, classification and methods of test.

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

Enquiry draft	Report on voting
104/508/DTR	104/537/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.

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

The committee has decided that the contents of this publication will remain unchanged until the stability date indicated on the IEC web site 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- withdrawn,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.

A bilingual version of this standard may be issued at a later date.

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ENVIRONMENTAL CONDITIONS – VIBRATION AND SHOCK OF ELECTROTECHNICAL EQUIPMENT –

Part 3: Equipment transported in rail vehicles

1 Scope

IEC/TR 62131-3, which is a technical report, reviews the available dynamic data relating to electrotechnical equipment transported by rail vehicles. The intent is that from all the available data an environmental description will be generated and compared to that set out in IEC 60721.

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 as to their quality and validity. The assessment also presents data for which the quality and validity cannot realistically be reviewed. These data are included to facilitate validation of information from other sources. The report clearly indicates when it utilizes information in this latter category.

This technical report addresses vibration and shock data from three different measurement exercises, i.e. one on the UK rail system and two on the USA rail system. Although one of these relates to a multimodal system in limited use world wide, data from it are included to facilitate validation of information from other sources. The vast majority of the rail measurements reviewed are from the USA and the remainder from Western Europe. Some of the data sources considered indicate the inclusion of some quite old vehicles. It has not been possible to identify the rail data considered in setting the existing IEC 60721 severities.

Although the majority of the measurement exercises considered in this technical report supplied both vibration and shock information, a number of measurement exercises are biased towards the shock conditions of rail transportation. The severity and incidence of shocks is mostly related to the occurrence shunting of individual wagons. The occurrence of shunting of individual wagons is in turn dependant upon the operational strategy adopted by the national rail systems. A significant number of rail systems no longer adopt methods of operation which assemble train sets when the wagons are carrying sophisticated goods (carriage of bulky raw minerals is a common exception). Other rail systems purposely utilize good quality wagons and/or procedures of operation to significantly mitigate shunting loads. These strategies are intended to minimize shock severities for sensitive equipment such as electrotechnical equipment.

Relatively little of the data reviewed have been available in electronic form. To permit comparison a quantity of the original (non-electronic) data have been manually digitized in this techical report.

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.

IEC 60068-2 (all parts), *Environmental testing – Part 2: Tests*

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

IEC 60721-3 (all parts), *Classification of environmental conditions – Part 3: Classification of groups of environmental parameters and their severities*

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

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*

3 Data source and quality

3.1 UK rail measurements

The vibration data in [1][1] from the UK rail system are relatively old (1980) and were commissioned by the UK MOD to summarize existing knowledge of the shock and vibration environments experienced by goods exposed to UK rail transit. The report initially sets out the five methods of operation used at that time within the UK. However, several of these are no longer adopted.

The report indicates that the major factors creating vibration environment within a vehicle are as follows:

– vehicle running gear characteristics (suspension, wheelbase, etc.);
– track condition;
– vehicle speed;
– vehicle lading condition.

This techical report contains vibration information indicated as from "worst case" vehicles (two axle, short wheelbase, simple suspension), intermediate suspension vehicles (longer wheelbase) and advanced suspension vehicles (long wheelbase, bogie good suspension and air brakes). The data are relatively low frequency (less than 100 Hz) but beyond the low pass filter frequency (10 Hz to 20 Hz – the report is not specific as to the actual roll-off frequency). The report admits that higher frequency content does exist but has no general information. Although it does indicate that with a rail sleeper spacing of approximately 0,7 m, a vertical component between 20 Hz and 40 Hz would be expected for speeds of 50 km/h to 100 km/h. The report does not supply any information as to the statistical errors on the measured data including the duration of measurements. Nor are any specific information supplied as to the exact location of the transducers or the specific vehicles used.

The report indicates that shocks, particularly longitudinally, can occur between two vehicles during running as a consequence of vehicle-to-vehicle interaction arising from traction, braking and gradient effects. The severity of such shocks is generally determined by the vehicle coupling arrangement and braking condition. Vehicles may be equipped with vacuum brakes, air brakes or none at all. Coupling between wagons may allow longitudinal movement (loose coupled) or none at all (tight coupled).

The report indicates that major shocks are attributed to heavy impact shunting in marshalling yards. The shocks severity is dependant upon impact speed, buffering gear characteristics and total mass of the wagon. The report explains two types of buffer are used: spring and hydraulic. The older spring buffers limit longitudinal accelerations until the springs close solid, typically at an impact speed of approximate 8 km/h, after which the acceleration levels rise rapidly. As the springs are linear energy storage systems, when the stored energy is released it can cause "shuttling" of the vehicles. As springs are linear, the impact shock is approximate to a classic half sine. Hydraulic buffers are fitted to newer wagons and are specifically intended to mitigate

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

impact shock. They are designed to give a more constant retardation over the entire impact speed range which is usually far greater than for spring systems. The amount of energy released into “shuttling” is also significantly reduced. The impact shock characteristics approximate to a trapezoidal pulse. The report sets out a distribution of actual shunting impact velocities (reproduced in Figure 3).

Overall, the data in the report cannot be considered adequate to meet the required criteria for data quality (single data item). This is largely because the source and statistical quality of the data cannot be established. The report is included, nevertheless, mostly because it sets out a good background to the source and influences on both the rail shock and vibration environment.

3.2 Association of American Railroads – Lengthways shocks

This relatively recent (1995) document (see [2]) from the Association of American Railroads is on the measurement and analysis of lengthwise rail shocks. Although the title of the document infers a description of a measurement and analysis exercise, in reality the majority of the report comprises a general background discussion. As a consequence, it is not a straightforward exercise to determine whether the data source meets the required criteria. The data source relates entirely to shunting shocks on the US system. The report contains tabulated longitudinal shock information relating to impacts between

– standard draft gear cars into standard draft gear cars at velocities of 1,8 m/s – 2,7 m/s (4 mph to 6 mph),
– M921 cushioned cars into standard draft gear cars at velocities of 1,8 m/s – 3,8 m/s (4 mph to 8,6 mph),
– M921D cushioned cars into standard draft gear cars at velocities of 1,8 m/s – 3,6 m/s (4 mph to 8 mph) ,
– M921 cushioned cars into M921 cushioned cars at velocities of 1,8 m/s – 3,6 m/s (4 mph to 8 mph) ,
– M921D cushioned cars into M921 cushioned cars at velocities of 1,8 m/s – 3,7 m/s (4 mph to 8,4 mph) ,
– M921D cushioned cars into M921D cushioned cars at velocities of 1,8 m/s – 3,7 m/s (4 mph to 8,4 mph) ,
– cushioned cars into cushioned cars (type unknown) at velocities of 1,3 m/s – 4,0 m/s (3 mph to 9,0 mph).

The document indicates that the standard draft gear cars are spring buffered with around 85 mm of buffer travel and little damping. The cushioned cars are hydraulic buffered with between 250 mm and 500 mm of buffer travel. The measurements were made at a sample rate of 256 samples per second (sps) and with an anti-aliasing filter set at 60 Hz. For each impact a record of duration 2 s was acquired (although none of the shocks appeared to utilise that record window). It is implied that the measurements were made with only a single tri-axial transducer probably embedded within an EDR-3 digital recorder. The actual location of the transducers / EDR-3 is not indicated. Rail impact velocities were acquired using a radar gun (accuracy unstated). The integral EDR-3 transducer is usually piezo-resistive and able to resolve to DC. As such would be a good choice for the measurement of long duration pulses under consideration by this work.

The report presents peak positive acceleration, peak negative acceleration, r.m.s. and crest factor for 60 Hz filtered data, for 10 Hz filtered data and 3 Hz filtered data. Based upon the 10 Hz and 3 Hz filtered data the shock duration and velocity change are derived. The latter is compared with measured car impact velocity. A considerable proportion of the report is expended in establishing this velocity comparison.

The data in the report is specifically related to the shunting shock conditions. It cannot be considered adequate to meet the required validated criteria for data quality (single data item). This is largely because the source and statistical quality of the data cannot be established. However, the information has a degree of traceability and realistically is the best available.

3.3 Association of American Railroads – Intermodal environment

This relatively recent (1991) work from the Association of American Railroads (see [3]) 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 clearly to establish the relationship between the vibration and shock conditions experienced during rail and road movements. The technical summary provides a description of a measurement and analysis exercise and presents some of the results. Whilst establishing the validity of the data and quality of the exercise from the technical summary alone is not straightforward, the source is supported by separate technical reports for each of the phases (see [4], [5] and [6]). Further, an “executive summary” report is also available (see [4]), some of which is reproduced below. The data source relates almost entirely to ISO containers on the US and Canadian rail system.

The study was divided into three phases:

- *Phase One:* A standard 27 m (89 foot) trailer on flat car (TOFC) was loaded with two trailers and moved in excess of 14 500 km (9 000 miles) over mountains, rolling hills and level terrain on U.S. and Canadian transcontinental routes.
- *Phase Two:* Four loaded, standard 12 m (40 foot) ISO containers were moved in dedicated intermodal trains over more than 18 000 km (10 900 miles) in principal U.S. rail corridors. The test containers were moved in double-stack rail cars, on articulated container on flat car (COFC) cars and articulated TOFC cars. Articulation is a way of joining rail cars to eliminate slack motion between them.
- *Phase three:* A 14 m (45 foot) intermodal trailer travelled more than 4 200 km (2 600 miles) of interstate highways, 1 900 (3 050 km) miles of primary (non-interstate) highways and 2 253 km (1 400 miles) of urban streets. Data was also collected for lift-on/lift-off operations at several intermodal ramps.

The report indicates differing data recording systems were used in the different phases. For phase 1 both an 18 channel data acquisition system was used as well as six self contained data recorders. Two data recorders were installed on each test trailer and container. The multi-channel system sampled at 128 sps with a filter at 30 Hz. The total record duration was around 11 % of a total of 4 200 km (2 600 miles) of rail transport. The six self contained units measured mostly shocks and adopted a sample rate of 1 600 Hz into 0,5 s files. The remaining two phases utilized two self contained recorders. One recorder was programmed to record random vibration data at preset intervals with a threshold of 0,1 g. The other recorder was set to record only acceleration levels exceeding a preset 0,5 g threshold, providing shock data for each test vehicle. The two pre-programmable data recorders, housed longitudinal, lateral and vertical accelerometers capable of DC measurement (piezoresistive). The sample rate was 250 sps in both cases.

The information in this report is limited to large 12 m (40 foot) ISO containers and the US/Canadian rail systems. However, the quality of the information is good and meets the required validation criteria for data quality (single data item).

3.4 Association of American Railroads – Study of the shock and vibration environment in boxcars

This relatively recent (1992) work from the Association of American Railroads (see [8]) is on the measurement and analysis of vibration and shock conditions experienced in both standard and cushioned boxcars. A lot of commonality exists between this study and that reported above. Data were recorded on some 16 journeys covering nearly 40 000 km (25 000 miles) and encompassed 14 different boxcars. The instrumented boxcars had a range of payloads and were located at different positions within the train set. Each boxcar had between 2 and 4 pre-programmed data recorders each with a single integral triaxial piezoresistive accelerometer. One recorder was programmed to record 4 s of random vibration data at preset intervals with a threshold of 0,1 g. The other recorder was set to record 2 s of data but only when acceleration levels exceeded a preset 0,5 g threshold for 15,6 ms, providing shock data for each test vehicle. In both cases the recorder sample rate was 256 sps. One pair of recorders was positioned as close to the centre of the payload bay floor as possible.

The study report, as was the case also in the previous study, presents amplitude probabilities for the shock data and PSD data for the vibration data.

The information in this report is limited to boxcars on the US rail system. However, the quality of the information is good and meets the required validation criteria for data quality (single data item).

3.5 Association of American Railroads – Study of the railroad shock and vibration environment for railroader equipment

This relatively recent (1992) work from the Association of American Railroads (see [9]) is on the measurement and analysis of vibration and shock conditions experienced by trailers carried on Mk IV and Mk V railroader equipment. A lot of commonality exists between this study and the two previous studies. Data was recorded on two different routes encompassing two types of railroader equipment. Eight different payloads were utilised four for each type of railroader equipment, however, these were not identical in the two cases. Each instrumented trailer had 2 pre-programmed data recorders, each with a single integral triaxial piezoresistive accelerometer. One recorder was programmed to record 4 s of random vibration data at preset intervals with a threshold of 0,1 g. The other recorder was set to record 2 s of data but only when acceleration levels exceeded a preset 0,5 g threshold for 15,6 ms, providing shock data for each test vehicle. In both cases the recorder sample rate was 256 sps. One pair of recorders was positioned as close to the (presumably rear) door threshold laterally centred on the payload bay floor.

The study report, as was the case also in the previous study, presents amplitude probabilities for the shock data and PSD data for the vibration data.

The information in this report is limited to a particular type of equipment which allows road vehicles to be moved by rail on the US rail system. Again the quality of the information is good and meets the required validation criteria for data quality (single data item).

3.6 Supplementary data

The data collection exercise which preceded this assessment also identified relevant sets of information which come from reputable sources but for which the data quality could not be adequately verified. Although, they are included here to facilitate validation of data from other sources, care should be taken when utilizing information in this category.

Johnson. In the mid 1970's G.E. Johnson of Cambridge Consultants in the UK was funded by the UK MOD to review the transportation shock environment. The final report of this work (see [10]) was delivered in 1976 and includes a significant review of available rail shock data. The shocks reported were all from inter-wagon impacts during shunting. The report includes a number of references containing rail shunting shock data. However, these are all pre-1970 and many relate to unobtainable data sources (hence are not reproduced here). Further the information set out by Johnson on shutting practice (Figure 28) are not representative of the practice used on the UK rail system in recent years.

Various US rail vehicles circa 1970. As part of an exercise, in the early 1970's, to authenticate test severities for the US military specification Mil Std 810, J.T. Foley (see [11]) at Sandia National Laboratories in the US undertook an extensive exercise to establish transportation severities on a number of platforms including several rail vehicles. As far as can be determined the vehicles used real US rail roads and conditions. The vibration information included data from 3 journeys and "other" (source unknown) published data. A total of 22 events were summarized up to 350 Hz. Whilst several measurements were considered, the process adopted does not allow information from individual vehicles to be identified. Moreover, the analysis process Foley used throughout his work is relatively unique and not immediately compatible with other information presented in this assessment.

Wagon GDE capacité. Information is contained within the French military specification GAM EG 13 (see [12]) from three different vehicles. The measurements were made on a variety of real rail conditions and speeds (although the exact nature is not known). All the data are presented in the form of PSD's of 1 Hz (or better) frequency resolution. The duration of the records used for the analysis is unknown and hence the analysis random error cannot be determined. Overlaid vibration spectra for the one vehicle are presented for vehicle speeds of 90 km/h, 100/h km and 120 km/h, respectively. Additionally shock response spectra for impacts at 4 km/h and 7 km/h are presented.

Miscellaneous data. During the course of the data search a number of possible data sources were identified for which the data were not traceable to any reasonable extent. These are included here for completeness because they may help support information from more traceable sources. Most of these sources are courtesy of Dr Ulrich Braunmiller and the EC sponsored SRETS work. Vertical responses from two rail vehicles presented in ASTM D4728-91 (see [13]). However, these data may well be those of the Association of American Railroads – Intermodal environment. The SRETS work also documents data from the UK Defence Standard Def Stan 00-35; which are based upon the UK Rail measurements already documented.

4 Intra data source comparison

4.1 General remark

The purpose of the following paragraphs is to review each data source for self consistency. The process for evaluating the vibration data takes into account the variation of vibration due to operational usage and aircraft characteristics. The level of confidence resulting from this review directly influences the levels of factoring and enveloping that are used when deriving environmental severities.

4.2 UK Rail measurements

The report from the UK rail system (see [1]) makes a number of comparisons but does not set out the basis for these. With regard to vibration the report suggests that vertical vibrations are marginally more severe than lateral, whilst longitudinal vibrations are usually insignificant. However, the report does indicate this vehicle possesses simple suspension, which is a lot worse in the vertical axis (these simple vehicles are essentially all used for transportation of minerals). The report contains limited vibration information which are shown in Figures 1 and 2 and relate to vehicle vertical and lateral axes. Summary amplitude information are summarized in Table 1.

The report indicates that longitudinal shocks can occur between two vehicles during running as a consequence of vehicle to vehicle interaction arising from traction, braking and gradient effects. The severity of such shocks is generally determined by the vehicle coupling arrangement and braking condition. Vehicles may be equipped with vacuum brakes, air brakes or none at all. Coupling between wagons may allow longitudinal movement (loose coupled) or none at all (tight coupled). Typical maximum longitudinal shocks are given as

– tight coupled, fully braked 0,2 g,
– loose coupled, fully braked 0,5 g,
– loose coupled, unbraked 2,0 g.

The report indicates that major shocks are attributed to heavy impact shunting in marshalling yards. The shock's severity is dependant upon impact speed, buffering gear characteristics and total mass of wagon. The report explains two types of buffer are used spring and hydraulic. The report indicates the longitudinal shock has the longest duration but not necessarily the greatest amplitude. Due to the position of the wagon centre of gravity (c of g) above the buffer height vertical shocks may be typically one and a half times greater in acceleration amplitude than longitudinal shocks but with a duration of only 10 ms. The severity of lateral shocks is more variable but can have the same greater acceleration amplitude as longitudinal shocks but with a duration of only 20 ms. Typical maximum longitudinal acceleration values are given as

– spring buffers, fully laden wagon until buffers fully compressed = 1,5 g,

– spring buffers, lightly laden wagon until buffers fully compressed = 3,0 g,

– spring buffers, fully laden wagon after buffers fully compressed = >15,0 g,

– hydraulic buffers, fully laden wagon at 8 km/h impact = 2,0 g (double for lightly laden wagon),

– hydraulic buffers, fully laden wagon at 15 km/h impact = 4,0 g (double for lightly laden wagon).

The report does not set out the basis for the derivation of these values.

4.3 Association of American Railroads – Lengthways shocks

This relatively recent (1995) document from the Association of American Railroads is solely on the measurement and analysis of lengthwise rail shocks. Whilst, the report extracts several indicators of a rather obvious nature, it does present a useful selection of summarized data from which the reader to make their own assessment. The information presented includes peaks and r.m.s. values mostly filtered at 3 different frequencies. The report present typical longitudinal shock pulses from impacts with different types car (shown in Figure 4). The report also presents acceleration levels (positive and negative) for some 96 shunting impacts of different cars at a range of speeds (Figures 5 and 6). For the same impacts r.m.s. and crest factors are also presented (Figures 7 and 8). However, a significant observation of the report relates the energy of the longitudinal shock to the impact energy (Figure 9). The reports conclusions imply that better the buffer cushion system the lower the amplitude and longer the duration of the shock (Figure 10).

The shock data presented in this report indicates an underlying relationship between shock amplitude and duration for different vehicle types. However, some data clearly falls outside this trend and the data most notable in this regard are labelled "cushioned vehicle into cushioned vehicle – type unknown". The report does not comment on this anomalous data although question marks over its applicability exist.

4.4 Association of American Railroads – Intermodal environment

This work from the Association of American Railroads includes measurement and analysis of both vibration and shock conditions experienced by standard ISO containers when transported by both rail and road. Each of the phases was intended to measure vibration and shock conditions on different road and rail vehicles. The clear main intent of the assessment was a comparison between rail and road, but some inter rail vehicle comparisons are also possible. In particular a comparison between axes is included. The report includes a distribution of shock and vibration amplitudes and again this shows the peak amplitudes are part of a reasonable distribution and not based on a few anomalous results.

The findings from the shock measurements (summarized in Table 5) were as follows:

a) The distribution of acceleration shock levels was established for each type of equipment and mode of transport. Accurate comparison is not readily possible from the data presented. However, the summary shown in Table 5 indicates quite high values of standard deviation compared to the mean. This seems to originate from a few (<1%) values that are much greater in amplitude than the remainder. Overall this would suggest a very skewed distribution with extreme values occurring at a relatively low occurrence rate.

b) Lengthways Shocks. Figure 11 and Table 2 show the distribution of longitudinal shocks. As can be seen whilst distribution for the standard 27 m (89 foot) trailer-on-flatcar shock environment was generally the most severe in the lengthwise direction it did not produce the most severe extreme conditions.