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TECHNICAL REPORT

Environmental conditions – Vibration and shock of electrotechnical equipment – Part 4: Equipment transported in road vehicles

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IEC Central Office
3, rue de Varembé
CH-1211 Geneva 20
Switzerland
Email: inmail@iec.ch
Web: www.iec.ch

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INTERNATIONAL ELECTROTECHNICAL COMMISSION

ENVIRONMENTAL CONDITIONS – VIBRATION AND SHOCK OF ELECTROTECHNICAL EQUIPMENT –

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FOREWORD

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IEC/TR 62131-4, 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
104/509/DTR	104/538/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- withdrawn,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.

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ENVIRONMENTAL CONDITIONS – VIBRATION AND SHOCK OF ELECTROTECHNICAL EQUIPMENT –

Part 4: Equipment transported in road vehicles

1 Scope

IEC/TR 62131-4, which is a technical report, reviews the available dynamic data relating to electrotechnical equipment transported by road 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 [25][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.

This technical report primarily addresses data extracted from a number of different sources for which reasonable confidence exists as to the quality and validity. The report 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 utilizing 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 road (and test track) conditions covered. The vast majority of the road conditions are from Western Europe. It is believed that one of the data sources considered is that used to set the current IEC 60721 severities. However, review of that data indicates the inclusion of some quite old vehicles.

Relatively little 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 have been manually digitized.

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

3 Data source and quality

3.1 SRETS road and test track measurements

The Source Reduction by European Testing Schedules (SRETS) study ([1]), part-funded by the European Union, was a collaborative venture undertaken by 10 European agencies and companies. The purpose of the study was to establish new vibration and shock test severities for equipment subject to road transportation. These test severities were destined for a new

1 References in square brackets refer to the bibliography.

CEN and ISO test procedure for packaged equipment. The three year study was completed in 1999 and the final report (see ([1]) published by the EU.

The vibration and shock measurement phase of the work focused on two separate exercises (see Table 1).

The first exercise, undertaken in the UK, was to establish the vibration and shock experienced by typical goods in real road conditions. To that end, measurements were made without the knowledge of the vehicle driver at the payload to vehicle interface during transportation of the same goods over similar (550 km) routes on 19 separate occasions, using different vehicles of a similar class (38 tonne articulated HGV's). The vehicles (commercial haulers) and drivers were supplied, the drivers being entirely unaware of the measurement exercise.

By contrast, in the second exercise, the measurements made with the full knowledge of the vehicle driver, used two specific vehicles on controlled German test tracks employing professional test track drivers. This second exercise was aimed at comparing vehicles, trailers, payloads and road surfaces. The second set of measurements adopted two different trucks in three configurations (one with trailer) at different speeds on different surfaces. Summary information on the various vehicles and trailer is shown in Table 2. The measurement locations utilized for the three vehicles are shown in Figure 1.

Both measurement exercises used solid state digital recorders. Whilst the second exercise facilitated the use of continuous recording, the lengthy duration of the first exercise necessitated the use of intermittent recording. The latter were undertaken in both "signal triggered" mode (storing the 500 blocks of 2 048 points containing the largest amplitude measurements) and "time triggered" mode (storing a block of 2 048 points every 3 min). The recorder sample rate was 5 500 sps with a low pass butterworth filter set to 1 000 Hz. Each block of data comprised 2 048 data points and represents an event duration of 0,372 s.

The first measurements adopted a single triaxial transducer located on the bottom of a pallet of packaged, bottled whisky. The vehicle was loaded to full capacity with 16 similar pallets. As the pallets were not stacked (one pallet height only) this payload filled the volume of the vehicle at around 90 % of its maximum weight capacity. The use of measurements made without the knowledge of the vehicle driver, has the advantage that it potentially reflects real world conditions. However, it has the disadvantage that the validity of the data is difficult to verify. The SRETS report specifically addresses this aspect comparing the data with itself (using the 19 separate runs) and with the test track work using several techniques such as comparing group means and by use of "analysis of variance".

The SRETS study adopted a variety of different data analysis procedures including power spectral density (PSD), amplitude probability density (APD) and fatigue damage spectra (FDS). In total, three different methods of establishing vibration and shock test severities were adopted. The resultant test schedules were verified by using them to test four different products and comparing the resultant damage with those experienced in the real world. These exercises demonstrated that the tests induced similar damage to that occurring in practice at a slightly accelerated rate. However, the rate of damage appeared more representative than some existing tests. The SRETS study also addressed a number of practical testing limitations and addressed some novel testing strategies.

The measurements from the SRETS are stored digitally; however, intellectual property rights limit the extent this data can be circulated. Summary information is included here in Figure 2 to Figure 17.

3.2 CEEES 'round robin' 10 tonne truck measurements

Although the CEEES 'round robin' exercise (see [2]) was not a measurement exercise, it did subject the same piece of real world road transportation measurements to analysis by a number of different methods and by a range of agencies. The vibration data used for the CEEES work (Figure 18, Figure 19 and Figure 20) was some 55 min of continuously recorded vibration measurements. These data were supplied to some 20 different agencies in Europe for analysis. These participants made independent analysis of this data (Figure 21, Figure 22 and Figure 23).

The data used in the CEEES exercise measurements were only part of a larger measurement exercise, undertaken by Cranfield University, the major part of which involved continuously recorded vibration measurements (see [3]) on a journey from central UK to central Germany (Figure 24 and Figure 25). The exercise involved 12 channels of measurement (plus vehicle velocity) on two payloads with a single triaxial measurement at the cargo bed. The vehicle used was a 10 tonne vehicle, of early 1970's design, able to operate on and off-road (it had 4 x 4 capability). Though it was a military vehicle it was based upon a commercial chassis and included commercial modifications (an integral hydraulic hoist). In addition to the continuous exercise, some measurements were made over degraded roads and obstacles (Figure 26 and Figure 27) at the maximum speed the driver considered safe. The continuous and degraded road measurements for the basis for environmental information contained in the UK defence standard 00-35 Part 5 (see [17]) as well as contributing to the NATO document STANAG 4370.

The analysis undertaken on the measured data was in the form of PSD and APD, each of a 1 h journey segment and combined for the complete journey. Additionally APD analysis was undertaken of the vehicle velocity measurement to establish a realistic usage profile. Whilst this is of some interest, it has limited application to this work as the upper speed limit of the vehicle was somewhat less than that imposed of commercial vehicles.

Measurements were recorded on an analogue recorder with calibration equipment. The measurement frequency range was up to 500 Hz. The PSD analysis was undertaken with a frequency resolution of 1 Hz and the APD analysis with an amplitude resolution of 0,002 g. In both cases, the analysis duration was typically in 1 h segments with the composite analysis covering a period of over 7 h. As a consequence of the latter duration, the APD from the composite measurement has good statistical accuracy down to very low levels of probability.

3.3 Various vehicle measurements by Hoppe and Gerock

Work by Hoppe and Gerock was under taken in the early 1970's and the resultant data are reproduced in a number of publications (see [4] and [5]). These data appear to be the basis for the severities in a number of national standards and, as far as can be identified, are probably the original basis for the severities in IEC 600721-3-2. Although the vibration data presented is very limited, the scope of the shock data is sufficient to justify its inclusion here.

The work by Hoppe and Gerock involved some nine vehicle and trailers; these are detailed in Table 3. The vehicles are mostly of leaf suspension designs, reflecting the vehicles' ages ranging between 1946 and 1970. All the test drives were made on dry roads on a closed circular route of 25 km consisting of

– 70 % concrete and asphalt,
– 18 % damaged and repaired roads,
– 10 % rough unpaved roads,
– 2 % cobble stones.

In addition to the above, four level crossings were included in the route. Vehicle speeds varied between 35 km/h and 45 km/h within town limits and up to 70 km/h on open roads. On rough parts of the route, speeds were reduced to between 10 km/h and 20 km/h. The test drives were made with the vehicles loaded to different degrees.

Little vibration data are presented in the reference, with information limited to a typical spectra (Figure 28) and an envelope of the measurements (Figure 29) broken into trucks and semi-trailer/pull trailers. However, the reference contains some useful shock data reproduced in Table 4, Table 5 and Figure 30.

Triaxial acceleration measurements were made above the rear axle, vertically in the centre of the load platform, vertically at the side of the platform at the rear and vertically at the front of the platform in the centre. All six measurements were recorded simultaneously and continuously on an analogue FM recorder. The frequency range covered was 1 Hz to 1250 Hz. All PSD analysis was undertaken using a 3 Hz frequency resolution and a record duration of 32 s. The shocks were classified into eight amplitude levels and sixteen time increments.

3.4 Millbrook measurements on Landrover Defender

This 1998 measurement exercise (see [6]) was undertaken at the UK Millbrook test track by Millbrook test engineers for Hunting Engineering Ltd. The measurements were made as part of a proving exercise on electronic equipment installed in Landrover Defender model LR10 (SVIC 34 / C112) registration CD 70 AA. As implied by the registration, it was a military registered vehicle but had only cosmetic modifications from the commercial variant.

The measurement configuration was 4 triaxial accelerometers and a optical tachometer to determine vehicle velocity. All the measurements were recorded on a Millbrook supplied analogue tape recorder using fully calibrated and traceable equipment. Three of the measurement locations were on equipment shelves and on the rear floor of the cargo area. Recordings were made on the following tracks at Millbrook:

– Test 1: high speed circuit at 48 km/h (30 mph) and record duration 130 s;
– Test 2: rough road test at 16 km/h (10 mph) and record duration 46 s;
– Test 3: pave at 40 km/h (25 mph) and record duration 266 s;
– Test 4: hill route at normal speeds and record duration 366 s;
– Test 5: random waves and record duration 56 s;
– Test 6: severe waves at 16 km/hr (10 mph) and record duration 30 s;
– Test 7: cross country at normal speed and record duration 673 s.

All the results are presented in [6]. All analysis was undertaken using the same analysis software presenting data from each channel in a consistent way. Essential for each measurement channel and track, a typical time history is presented along with an APD and PSD. The sample rate was 1 024 sps producing a frequency resolution of approximatly 0,5 Hz. The record durations varied according to track surface and are indicated in the list above. The data is summarized here in terms of variations in vibration r.m.s. with road surface in Figure 31 and the variation in shock amplitude in Figure 32. The spectra for the vertical axis are shown in Figure 33.

3.5 Millbrook measurements on Ford transit van

This 1996 measurement exercise (see [7]) was undertaken at the UK Millbrook test track by Millbrook test engineers for Hunting Engineering Ltd. The measurements were made as part of a proving exercise on a communication installation in a (new) Ford Transit Van registration M639 BTL. The loading on the front axle was 1 248 kg, on the rear axle 969 Kg, giving a total of 2 217 Kg.

The measurement configuration was 3 triaxial accelerometers, 3 uni-axial accelerometers and a vehicle speed transducer. All the measurements were recorded on a Millbrook supplied analogue tape recorder using fully calibrated and traceable equipment. Most of the measurement locations were on equipment shelves but two triaxial measurements were in the cargo area (one over the rear axle and one in the centre of cargo area). Recordings were made on the following tracks at Millbrook:

a) Vibration

high speed circuit at 85 km/h and record duration 376 s;

gravel road test at 48 km/h (30 mph) and record duration 157 s;

B Class road (incl. level crossing) at 64 km/h (40 mph) and record duration 192 s;

b) Shocks

pot hole “A” and “B” at 16 km/h (10 mph);

Millbrook cat’s eyes at 48 km/h (30 mph);

railway level crossing at 32 km/h (20 mph).

Analysis was undertaken for each measurement channel and surface and a typical time history presented along with an APD and PSD. The sample rate was 1 024 sps, producing a frequency resolution of approximatly 0,5 Hz. The record durations varied according to track surface and are indicated in the list above. The data is summarized here in terms of variations in vibration r.m.s. with road surface in Figure 34, in terms of peak spectral value in Figure 35 and the variation in shock amplitude in Figure 36. The spectra for the vertical axis are shown in Figure 40.

3.6 Millbrook measurements on Renault Magnum

This 1996 measurement exercise (see [8]) was undertaken at the UK Millbrook test track by Millbrook test engineers for Hunting Engineering Ltd. The measurements were made as part of a proving exercise on a communication installation in a (new) Renault AE 385ti Magnum semi trailer with a box trailer equipped as a command and communication centre. The loading on the front axle was 5 764 kg, on the rear axle 8 985 Kg, giving a total of 14 749 Kg.

The measurement configuration was 1 triaxial accelerometer, 4 bi-axial accelerometers, 2 uni-axial accelerometers and a vehicle speed transducer. All the measurements were recorded on a Millbrook supplied analogue tape recorder using fully calibrated and traceable equipment. Most of the measurement locations were on equipment shelves but some (2 bi-axial) were directly mounted on the van sides of the trailer. All of the remainder had a very short transmission path to the van sides of the trailer. Recordings were made on the following tracks at Millbrook:

a) vibration;
b) high speed circuit at 85 km/h and record duration 347 s;
c) gravel road test at 32 and 48 km/h (20 and 30 mph) and record duration 197 s;
d) B class road at 48 and 64 km/h (30 and 40 mph) and record duration 254 s;
e) shocks;
f) Millbrook pot hole “A” and “B” at 16 km/h (10 mph) ;
g) Millbrook cat’s eyes at 48 km/h (30 mph);
h) Railway level crossing at 32 km/h (20 mph).

Analysis was undertaken for each measurement channel and surface, with a typical time history presented along with an APD and PSD. The sample rate was 1 024 sps, producing a frequency resolution of approximately 0,5 Hz. The record durations varied according to track surface and are indicated in the list above. The data is summarized here in terms of variations in vibration r.m.s. with road surface in Figure 37, in terms of peak spectral value in Figure 38 and the variation in shock amplitude in Figure 39. The spectra for the vertical axis are shown in Figure 40.

3.7 Supplementary data

The data collection exercise which preceded this assessment identified several 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.[2]

Renault Trafic (1,9 tonne) and TRM 1000 (20 tonne). Information is contained within the French military specification GAM EG 13 (see [9] from two different vehicles. The 4 x 2 Renault Trafic was loaded to an all up mass of 1 950 Kg and triaxial acceleration measurements made at two locations designated only as “central platform” and less specifically “longeron ArG”. The triaxial acceleration measurements on the TRM 1000 were made on the chassis. The measurements were made on a variety of real road conditions and specific surfaces (whether these are real road surfaces or test tracks 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. A summary of the r.m.s. variations with road surface and vehicle speed are presented in Table 6 and Table 7 for the Renault Trafic and TRM 1000 respectively. Overlaid spectra for the two vehicles are also presented in Figure 41 and Figure 42.

Various US road vehicles circa 1970. As part of an exercise, in the early 1970’s, to authenticate severities for the US military specification Mil Std 810, J.T. Foley (see [10]) at Sandia National Laboratories in the US undertook an extensive exercise to establish transportation requirements on a number of platforms including several road vehicles. As far as can be determined, the vehicles used real US roads and conditions. The vehicles included

a) well used tractor – flatbed trailer with leaf springs suspension,

b) renewed tractor – flatbed trailer with leaf spring suspension,

c) well used tractor van trailer with air ride suspension,

d) new tractor – van trailer with air ride suspension,

e) carefully driven tractor – van trailer with leaf spring suspension,

f) 2,5 tonne flatbed truck of conventional commercial design,

g) 2,5 tonne van truck modified to carry explosives.

The measurements encompassed seven road vehicles but 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. Foley generated test spectra (Figure 43) which can be usefully compared with those from other methods and sources.

Various US road vehicles circa mid 1980’s. As part of an exercise, in the mid 1980’s, to authenticate test severities for the US military specification Mil Std 810, William Connon (see [11]) at the US Army Aberdeen proving ground, undertook an extensive exercise to establish severities on a number of platforms including several road vehicles. The measurements were entirely made on the special test tracks at the Aberdeen proving ground. The (essentially military) vehicles included

(1) M127 12 tonne semi-trailer,

(2) M813 5 tonne truck,

(3) M814 5 tonne truck,

(4) M36 2,5 tonne truck,

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2 Landrover Defender Model LR10 (SVIC 34 / C112) Registration CD 70 AA, Ford Transit Van Registration M639 BTL, Renault AE 385ti Magnum Semi Trailer, Renault Trafic (1,9 tonne), Renault TRM 1000 (20 tonne), as well as various US Military road vehicles, are the trade names of products supplied by Renault, Ford and the US Military, respectively. This information is given for the convenience of users of this technical report and does not constitute an endorsement by IEC of the products named.

(5) CUCV M1009 1,5 tonne truck,

(6) HMMWV M998 1,25 tonne truck,

(7) HEMTT M985 10 tonne truck,

(8) M416 0,25 tonne 2 wheeled trailer,

(9) M105A2 1,5 tonne 2 wheeled trailer.

The measurements encompassed nine different vehicles but the process adopted does not allow information from individual vehicles to be identified. Moreover, the analysis process used throughout the work is relatively unique and not immediately compatible with other information presented in this assessment. Connon generated test spectra (Figure 44) which can be usefully compared with those from other methods and sources.

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 SRETS work. Vertical responses from several road surfaces presented in ASTM D4728-91 (see [12]) are shown in Figure 45. Multi-axis responses from a trailer originating from ASTM D4728-95 (see [13]) are shown in Figure 46 and for a semi-trailer in Figure 49. The vertical vibrations from a 15 tonne truck originating from EXACT DK 1-237 ([14]) are shown in Figure 47. Information from a trailer with leaf springs ([15]) are shown in Figure 48. Lastly information from an intermodal study ([16]) are shown in Figure 50.

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 variations arising from vehicle type, road surface, vehicle velocity and vehicle loading. Whilst historical evidence suggests that all of these have some influence on vibration severity, the same evidence also suggests an even bigger influence may be the way the vehicle is driven.

4.2 SRETS road and test track measurements

The SRETS work specifically undertook an intra and inter data source comparison to verify the quality of the data acquired. For the overtly acquired data specific comparisons were made between vehicle type (Figure 8), road types (Figure 9) and vehicle load (not included). These information are also summarized in Figure 5. The entire basis for the covertly acquired data was to maintain practically similar vehicle class, road route and vehicle load conditions. The very purpose was to quantify the variations arising from any other practical influence including the way the vehicle is driven. Shown in Figure 2 and Figure 3 are the variations from 18 journeys of which 16 (journeys 4 to 19) were nominally identical.

Analysis of variance (ANOVA) calculations between the various data sets indicated that the covertly and overtly data sets are not significantly different to a level of confidence of 95 %, provided data acquired in a similar manner are compared. That is provided real road data are compared and the overtly acquired test track data are excluded (Figure 6). This appears reasonable as ANOVA calculations between the overtly acquired road data and overtly acquired test track data are significantly different. The other difference identified was between the covertly acquired “signal triggered” data and “time triggered” data. The difference between these two acquisition strategies are shown in Figure 10, Figure 11, Figure 12 and Figure 13. These figures also illustrate other aspects of covert measured environment. The SRETS workers observed a markedly greater variance in the covertly acquired data from similar overtly acquired data. This would appear to support the use of covert measurements.

The trends indicated by the SRETS assessment are summarized as follows: