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Li-Ion Batteries.
Standards for Shock and Vibration Tests

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There are quite many Shock and Vibration Test standards for batteries in electric vehicles

Here we make some remarks and comparisons of those standards.

Also some words about comparing Field Measurements with Standards.

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Some standards:

SAE J2380	Vibration testing of electric vehicle batteries	Random
IEC 62660-2	Secondary lithium-ion cells	Random
UN 38.3	Transport of batteries	Sine sweep
ISO 19453-6:2020	Traction battery packs and systems	Random, Shock
ISO 6469:1:2019	Safety specifications, Rechargeable	Random, Shock
ISO 12405	Li-ion battery systems	Random,Temp

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The standards mostly still treat the batteries as a component added to a vehicle.

No more! A car is becoming a battery on wheels!

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We need standards to treat the full vehicle!

Maybe too unpractical with old fashioned shaker vibration test!

Virtual testing only way forward?

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SURFACE VEHICLE RECOMMENDED PRACTICE	J2380	DEC2013
	Issued 1998-01 Revised 2013-12 Superseding J2380 MAR2009	
Vibration Testing of Electric Vehicle Batteries		

Test procedure to
Characterize the effect of Long-term, road-induced vibration and shock on performance and service life of electric vehicle batteries.

Either swept sine wave vibration or random vibration is typically used.

Random vibration is the focus of this document.
Impact testing, such as crash and pothole, is not included in this procedure.

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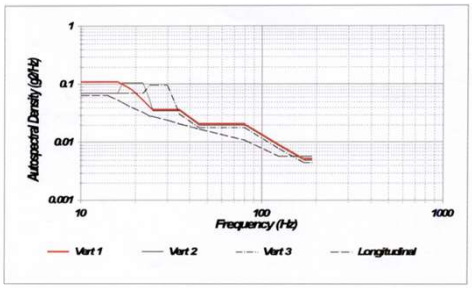

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TABLE 1 - VIBRATION SCHEDULE FOR RANDOM VIBRATION TEST

TEST CONDITIONS VIBRATION SPECTRUM	TEST CONDITIONS SOC (%)	NORMAL TEST Acceleration (g rms)	NORMAL TEST Time (h)	NORMAL TEST Cumulative Time, h	ALTERNATIVE TEST Acceleration (g rms)	ALTERNATIVE TEST Time (h)	ALTERNATIVE TEST Cumulative Time, h
Vertical Axis Vibration:							
Vertical 1 spectrum	100	1.9	0.15	0.15	1.9	0.15	0.15
Vertical 1 spectrum	100	0.75	5.25	5.4	0.95	3.5	3.65
Vertical 2 spectrum	100	1.9	0.15	5.55	1.9	0.15	3.8
Vertical 2 spectrum	100	0.75	5.25	10.8	0.95	3.5	7.3
Vertical 3 spectrum	20	1.9	0.15	10.95	1.9	0.15	7.45
Vertical 3 spectrum	20	0.75	5.25	16.2	0.95	3.5	10.95
Longitudinal Axis Vibration:							
Longitudinal spectrum	60	1.5	0.09	16.29	1.5	0.09	11.04
Longitudinal spectrum	60	0.4	19.0	35.29	0.75	6.7	17.74
Longitudinal spectrum	60	1.5	0.09	35.38	1.5	0.09	17.83
Longitudinal spectrum	60	0.4	19.0	54.38	0.75	6.7	24.53
Lateral Axis Vibration:							
Longitudinal spectrum	60	1.5	0.09	54.47[1]	1.5	0.09	24.62[1]
Longitudinal spectrum	60	0.4	19.0	73.47[1]	0.75	6.7	31.32[1]
Longitudinal spectrum	60	1.5	0.09	73.56[1]	1.5	0.09	31.41[1]
Longitudinal spectrum	60	0.4	19.0	92.56[1]	0.75	6.7	38.11[1]

1. These cumulative times apply only if all three axes are done separately.

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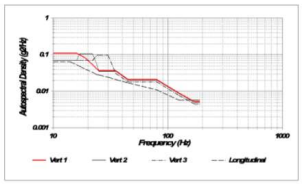
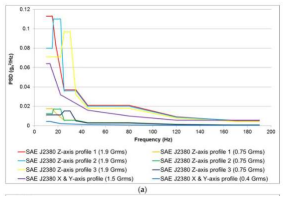


SAE J2380 Random Test Profile



(a)

No tables in the standard, creates confusion!
Straight lines in log/log or lin/lin?

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SVENSK STANDARD SS-EN IEC 62660-2

SEK SVENSK ELSTANDARD

Fastställd	Utgåva	Sida	Ansvarig kommitté
2019-03-13	2	1 (1+21)	SEK TK 21

Laddningsbara batterier –
Litium-jonceller för elfordon –
Del 2: Provning av funktionssäkerhet och tålighet mot felaktig hantering

Secondary lithium-ion cells for the propulsion of electric road vehicles –
Part 2: Reliability and abuse testing

IEC 62660-2 is a test for testing cells. Cells have small dimensions and therefore higher critical frequencies can be expected.
This test is more severe, especially for higher frequencies.

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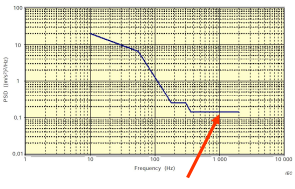
PSD is given in tables and figures. Note SI units!

Table 2 – Values for PSD and frequency

Frequency Hz	PSD $(m/s^2)^2/Hz$
10	20
55	6.5
180	0.25
300	0.25
360	0.14
1 000	0.14
2 000	0.14



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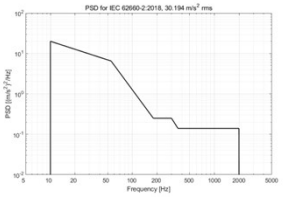
b) Perform the test referring to IEC 60068-2-64 random vibration. Use test duration of 8 h for each plane of the test cell.

c) The RMS acceleration value shall be 27,8 m/s^2. The power spectrum density (PSD) plotted against frequency is shown in Figure 2 and Table 2. The maximum frequency shall be 2 000 Hz.



They have obviously extended the frequency range to 2000 Hz, and forgot to recalculate the rms. ☺

$$\sqrt{30.194^2 - 0.14 \cdot (2000 - 1000)} =$$

$$\sqrt{911.6747 - 140} =$$

$$\sqrt{771.6747} = 27.78$$

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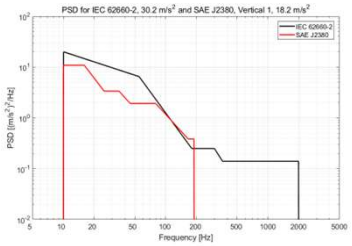
A comparison of IEC 62660-2 and SAE J2380
Test duration 8 h and 0.15 h respectively



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Shock

6.2.2.2 Test

The test shall be performed as follows.

a) Adjust the SOC of the cell to 100 % for BEV application and to 80 % for HEV application in accordance with 5.3.

b) Perform the test in accordance with ISO 16750-3 as shown in Table 3. Acceleration from the shock in the test shall be applied in the same direction as the acceleration of the shock that occurs in the vehicle. If the direction of the effect is not known, the cell shall be tested in all six spatial directions.

Table 3 – Mechanical shock test – parameters

Pulse shape	half-sinusoidal
Acceleration	500 m/s²
Duration	6 ms
Number of shocks	10 per test direction

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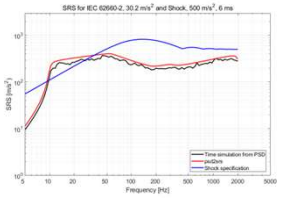
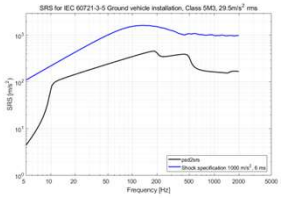
How about SRS for shock test and vibration test?
Compare with old IEC 60721-3-5 Ground Vehicle Installation





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UN 38.3 Transportation of Lithium Batteries, contains
requirement to ensure the safety of lithium batteries during shipping.

- ❑ Sinusoidal waveform
- ❑ Logarithmic sweep from 7 Hz to 200 Hz and back to 7 Hz in 15 minutes.
- ❑ Cycle shall be repeated 12 times for a total of 3 hours
- ❑ Each of three mutually perpendicular mounting positions of the cell.
- ❑ The logarithmic frequency sweep is as follows:
  from 7 Hz a peak acceleration of 1 g is maintained until 18 Hz is reached.
- ❑ The amplitude is then kept at 0.8 mm until a peak acceleration of 8 g.
- ❑ Peak acceleration of 8 g is then maintained until the frequency is increased to 200 Hz.

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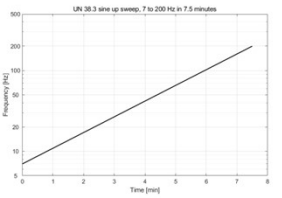
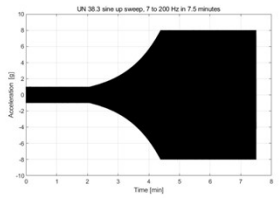
A simulation of the sine sweep in UN 38.3





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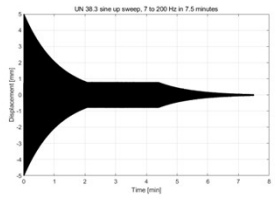
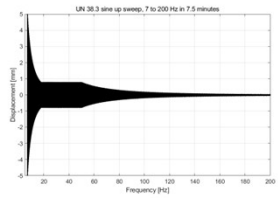
A simulation of the sine sweep in UN 38.3





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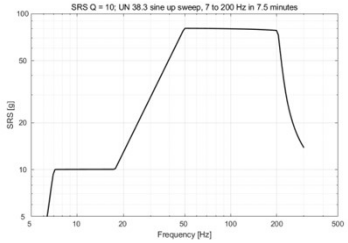
May be used for simulations and comparisons



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SVENSK STANDARD
SS-ISO 19453-6:2020

Vägfordon – Miljökrav och miljöprovning för el- och elektronikutrustning i drivsystem för elfordon – Del 6: Batterier (ISO 19453-6:2020, IDT)

8.4 Structural durability and strength tests
8.4.1 General
8.4.2 Fixture
8.4.3 Pre-conditioning for mechanical tests
8.4.4 Durability test
8.4.5 Mechanical shock
8.4.6 Requirements

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Three categories defined

Table 6 — Fixture type for structural durability and strength test depending on DUT category

Battery pack or system category	Fixture type
1	Rigid mounting on the base plate
2	As agreed between customer and supplier: rigid mounting on the base plate or vehicle mounting equipment, such as carrying frame or brackets, according to the given drawing instructions by the manufacturer
3	Vehicle mounting equipment, such as carrying frame or brackets, according to the given drawing instructions by the manufacturer

PSD vehicle specified (tailoring) or from tables in standard

Accelerated test may be used, standard says 40 h each direction

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Table 7 — Mechanical load

	Category 1	Category 2	Category 3
Test method	Uniaxial shaker in X, Y, Z-direction	Uniaxial shaker in X, Y, Z-direction or MAST	Uniaxial shaker in X, Y, Z-direction or MAST Additional loads, including but not limited to torsion and bending, if necessary.
Test profile	PSD profiles for category 1 or vehicle specific profiles	PSD profiles for category 2 or vehicle specific profiles	Vehicle specific profiles and testing time or vehicle specific time signals

MAST = MultiAxial Simulation Table
Coming IEC standard IEC 60068-2-xx
Category 3 has added temperature cycling

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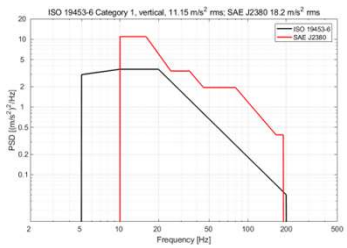
ISO 19453-6:2020 Traction battery packs and systems
Random, Shock. PSD example, category 1, vertical direction



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ISO 19453-6 shock tests. Same 6ms half sine!
20g, 13g, 30g for X, Y, Z. IEC 62660-2 has 51 g

Table 17 — Mechanical Shock load for DUTs of category 1 to 3

	Category 1	Category 2	Category 3
Shock wave form	Half-sinusoidal		
Shock duration	6 ms or OEM specific		
Number of shocks at SOC_{min}	3 per test direction ±X, ±Y, ±Z (total 18)		
Number of shocks at SOC_{max}	3 per test direction ±X, ±Y, ±Z (total 18)		
Acceleration	X: 196,2 m/s² or OEM specific Y: 127,53 m/s² or OEM specific Z: 294,3 m/s² or OEM specific	X: 176,58 m/s² or OEM specific Y: 98,1 m/s² or OEM specific Z: 245,25 m/s² or OEM specific	X: 147,15 m/s² or OEM specific Y: 78,48 m/s² or OEM specific Z: 196,2 m/s² or OEM specific
Operating mode	Operating mode 6.3		

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INTERNATIONAL STANDARD **ISO 6469-1**

Third edition
2019-04

Electrically propelled road vehicles — Safety specifications —

Part 1:
Rechargeable energy storage system (RESS)

6.2 Mechanical test
6.2.1 General
6.2.2 Vibration
6.2.3 Mechanical shock

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Values much lower than for other standards

Levels based on vehicle measurements (tailoring)

Table 1 — Values for the PSD in Z-direction

Frequency Hz	PSD $(m/s^2)^2/Hz$
5	0,048 1
10	0,577 4
15	0,384 9
200	0,010 4
RMS	2,64 m/s^2

Table 2 — Values for the PSD in X-direction

Frequency Hz	PSD $(m/s^2)^2/Hz$
5	0,028 9
20	0,288 7
200	0,010 4
RMS	2,34 m/s^2

Table 3 — Values for the PSD in Y-direction

Frequency Hz	PSD $(m/s^2)^2/Hz$
5	0,192 5
15	0,288 7
50	0,028 9
200	0,010 4
RMS	2,51 m/s^2

Requirement
Half-sinusoidal
±Z: 70 m/s^2
±X: 50 m/s^2
±Y: 30 m/s^2
6 ms
6 per test direction

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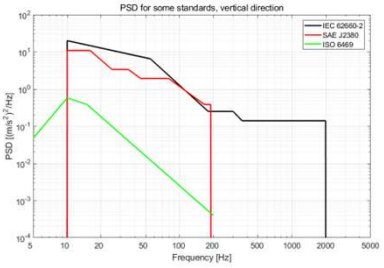

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	ISO 12405-1 *Electrically propelled road vehicles – Test specification for lithium-ion traction battery systems* *Part 1- High power applications*	
Object *Cell/Module/Pack/ Electronics*	Electronic devices on the batteries Same as **IEC 62660-2**	Pack (including electronics)
Directions	Three directions	Three directions
Vibration mode *Sinus/Random*	Random	Random
Frequencies *(Hz)*	10-2000	5-200
Acceleration *(g)*	3 (rms)	1.44 (rms)
Time/axis *(hour)*	8	21

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ISO 12405-4:2018

NOTE 1 Typical applications for high-power battery packs and systems are hybrid electric vehicles (HEVs) and some type of fuel cell vehicles (FCVs).

NOTE 2 Typical applications for high-energy battery packs and systems are battery electric vehicles (BEVs), plug-in hybrid electric vehicles (PHEVs) and some type of fuel cell vehicles (FCVs).

NOTE 3 Testing on cell level is specified in IEC 62660 series

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ISO 12405-4:2018
A general standard for testing Li-ion battery systems containing electric performance tests, reliability tests and abuse tests. Superseeding -1.

Vibration tests on two levels are suggested; one test for electric and electronic devices identical to IEC 62660-2

One test for battery and pack systems. The latter test is done as three uniaxial random tests at 5-200 Hz. During the vibration test the temperature should be varied between -40C, ambient temperature and +75C.

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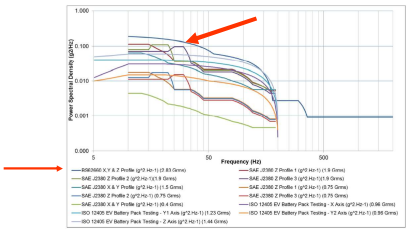
Some kind of summary (and misunderstanding)

SAE J2380, ISO12405 and BS62660 are illustrated at their desired test Grms levels in Figure 1. It must be noted that the severity of these test is difficult to compare using their PSD levels alone, as their severity is a combination of their PSD levels and their duration.



PSD in 62660 is defined by straight lines in loglog! 😡

Figure 1: Test profiles defined in SAEJ2380, ISO12405 and BS62660 at specified Grms levels

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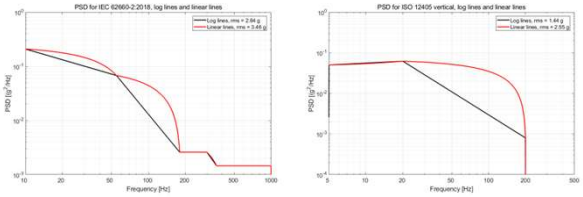
Be careful! ALWAYS check!



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The existing standards are in need of revisions!

Users' understanding is questionable!

I have studied some publications with comparison of field measurements and testing standards

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General Recommendations:

In a journal article:
Give complete information, even on details, so an interested reader is given the chance to repeat the "experiment" (mouse in maze)

In a report:
Add the details in an Annex.
I usually add the complete MATLAB scripts used

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FDS from standard test PSD, for comparison, from one publication

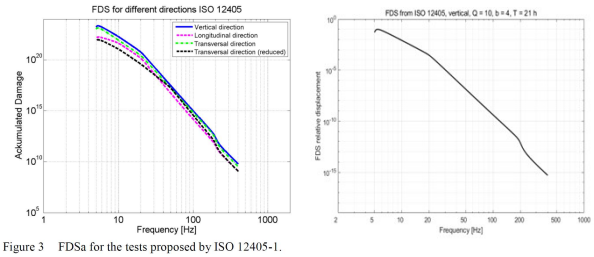

Figure 3 FDSa for the tests proposed by ISO 12405-1.

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There is a factor close to 10^{24}

Q = 10 ?

When calculating the FDS the relative damping of the SDOF system must be specified in order to get the amplitude of the response, in this paper it's assumed to be 5%. Further, it's assumed that

b = 4?

In the calculations the value of the Basquin coefficient, b, is set to 4. This is a material parameter

K = 1000

$$C = S^b N_f \qquad (1)$$

Where N_f is the life-length, and the stress, S, is obtained from

$$S = Kz(t) \qquad (2)$$

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I checked with author, and his software calculates relative displacement in [mm], not [m]. Irvine script?

That gives us a factor $(1000*1000)^b = 10^{24}$

Hopefully, the FDS from measurements are scaled the same way!

Check with simulation: PSD to time signal
Is PSD(time signal) = given PSD?
Is FDS(time signal) = FDS(PSD)?

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Correct with the factor 1.e24

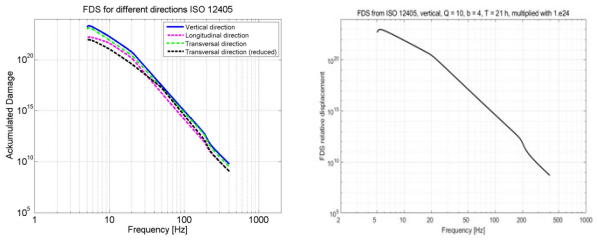

Figure 3 FDSa for the tests proposed by ISO 12405-1.

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How about FDS for UN 38.3 sine sweep?

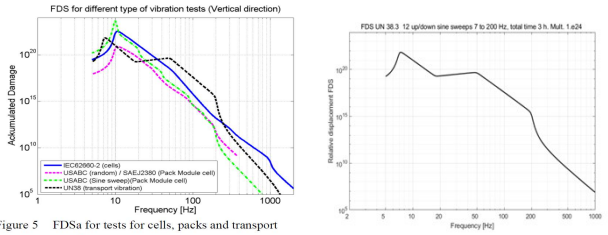

Figure 5 FDSa for tests for cells, packs and transport simulation.

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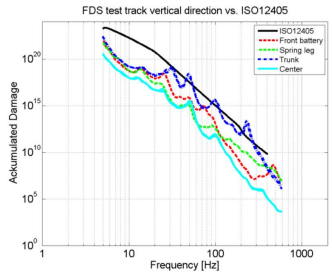
Example of FDS comparison for different measuring positions in the car



No spectrum analysis of the measurements or rms values are given in the paper, so it hard to check the calculations from time histories to FDS.

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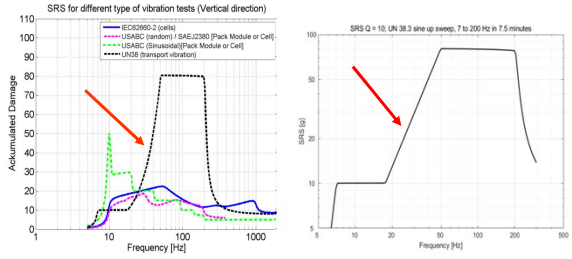
How about SRS, MRS? From UN 38 we find unit is g



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Another report from the guys with the misunderstanding of PSD defined by breakpoints

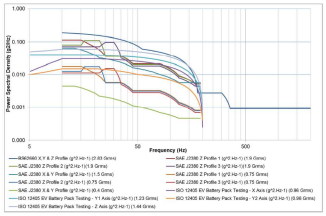

Figure 1: Test profiles defined in SAEJ2380, ISO12405 and BS62660 at specified Grms levels

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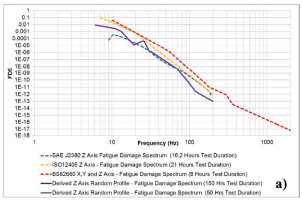
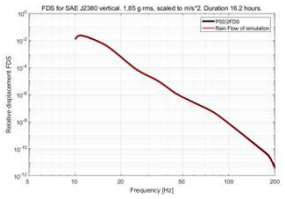
Another scaling of FDS, but in the text they refer to the other report (same words, copy/paste) including K =1000.





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Conclusions

- The existing standards are a bit of a mess, when it comes to mechanical tests and comparison with field measurements!
- The people in the business writing reports have a lot to learn!
  - ***For you:***
  - be sure to know what you are doing
  - get familiar with your used software
  - complement with own software
  - simulate, simulate, simulate!