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Defining a Representative Vibration Durability Test for Electric Vehicle (EV) Rechargeable Energy Storage Systems (RESS)

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Introduction and Background

- “Life representative” vibration durability tests play an important role in the selection of components.
- Ensuring that the battery maintains customer satisfactory performance over warranted life (e.g. 10 years or 100,000 miles of customer usage).



Introduction and Background

Limitations of previous research and test standards:

- 1) Used data from internal combustion engine cars and not EV's.
- 2) Used vibration measurements from a single road surface measurement.
- 3) Used profiles not correlated to a know durability life – 100,000 miles
- 4) Used vibration profiles which are unrepresentative of vibration environment of chassis mounted components.
- 5) Have compared test standards via their acceleration content.



Aims

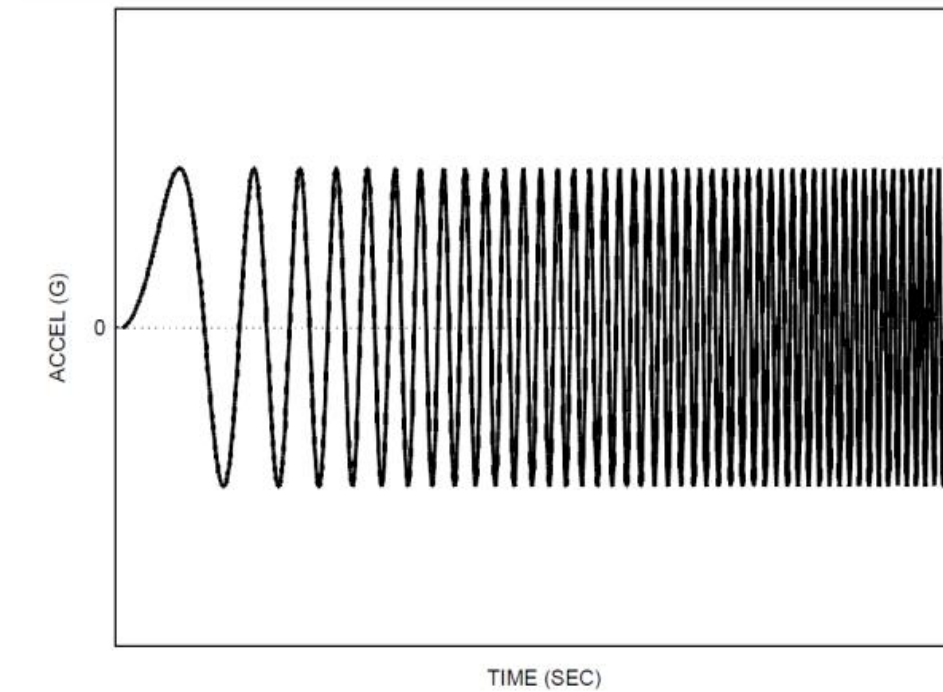
- To develop a set of “random” vibration profiles that are representative of 100,000 miles of UK customer usage of a chassis mount battery within an electric vehicle using actual EV measurements, that can assist future testing of EV components (Part 1).
- Use the derived vibration profile(s) to critically assess current random vibration test procedures via comparing the mechanical shock characteristic (SRS) and potential fatigue damage (FDS) (Part 2).



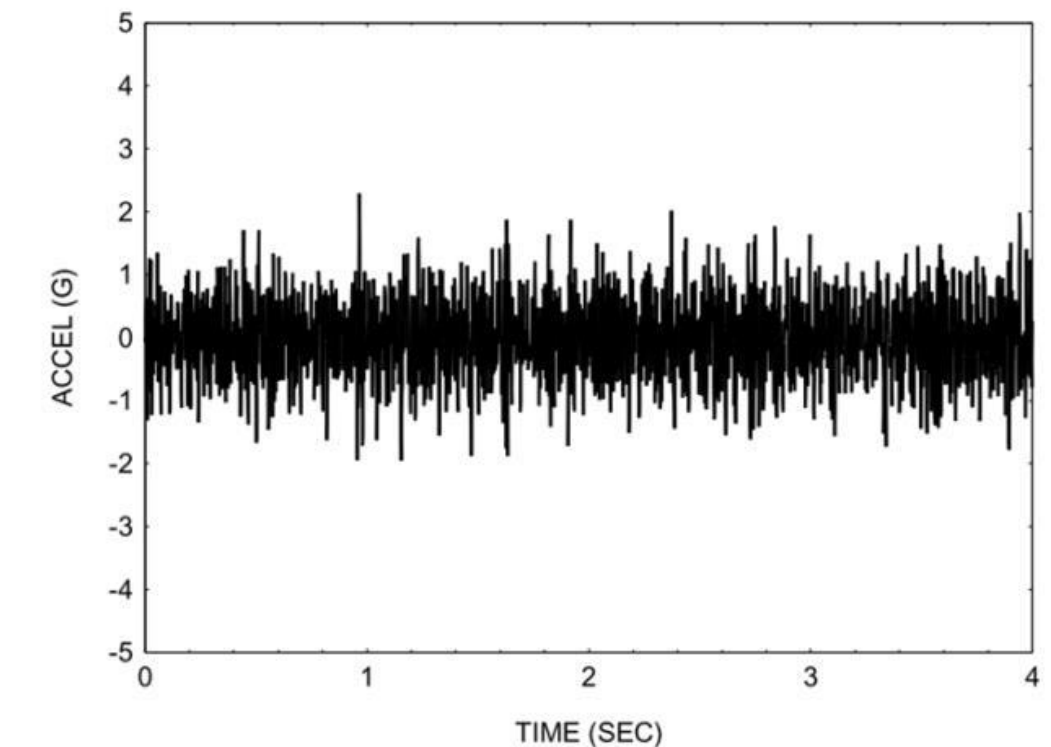


Part 1 - Developing a Representative Random Vibration Profile

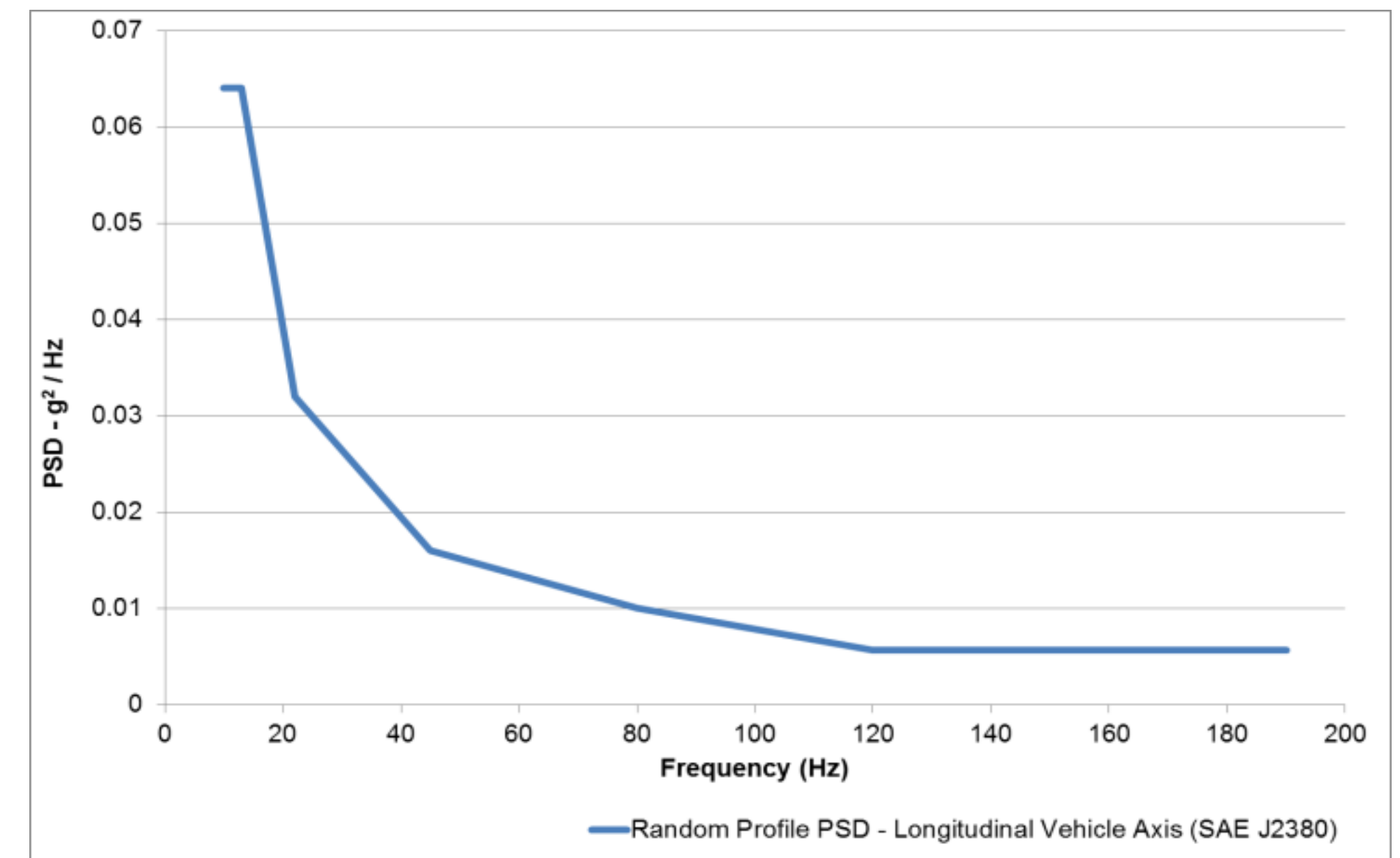
- Typically two types of frequency domain vibration profile used within the assessment of automotive components:
 - Swept Sine
 - Random
- Random profiles are more representative of chassis mounted components which are excited by road inputs.
- Random test profiles define acceleration as the average power seen in a 1 Hz bandwidth (g^2/Hz)



Swept sine – illustrated in time domain

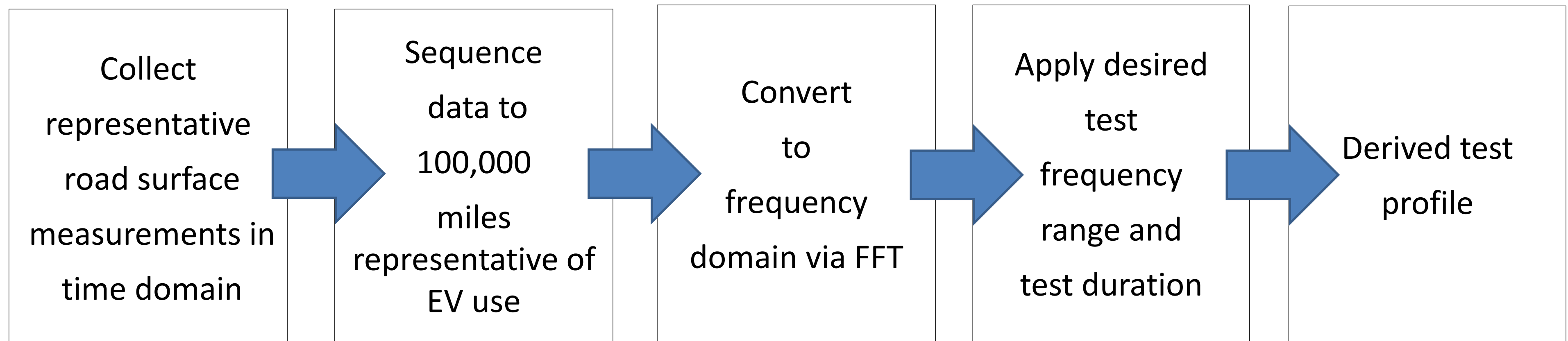


Random – illustrated in time domain





Part 1 - Developing a Representative Random Vibration Profile



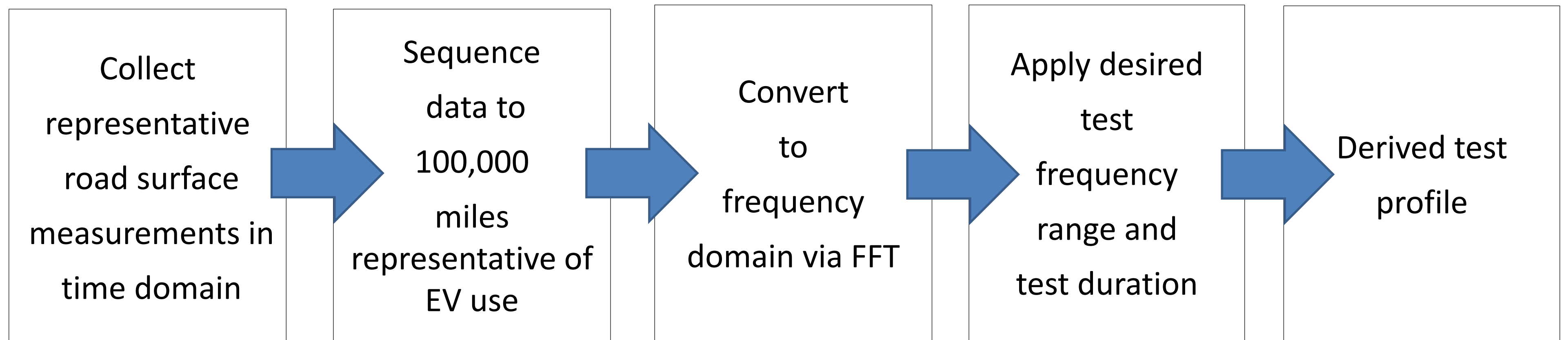
Collecting Representative Road Surface Data

- 3 x Battery Electric Vehicles:
 - Mitsubishi iMiEV
 - Smart ED
 - Nissan Leaf
- Tri-axial Accelerometers at front and rear of the battery pack
- Millbrook “Whole Vehicle Structural Durability” schedule used as framework for surface measurements
- Assessed over Urban, Rural and Motorway class surfaces at Millbrook Proving Ground





Part 1 - Developing a Representative Random Vibration Profile





Sequencing Data to 100,000 miles Representative of EV Use

- To determine correct EV surface weightings, study undertaken at University of Warwick where surface environments of users of a Nissan Leaf were evaluated.

Surface Classification	Surface Weighting - based on 2014 University of Warwick Study of BEV Journeys (%)
Urban	37.3
Rural	39.1
Motorway	23.5

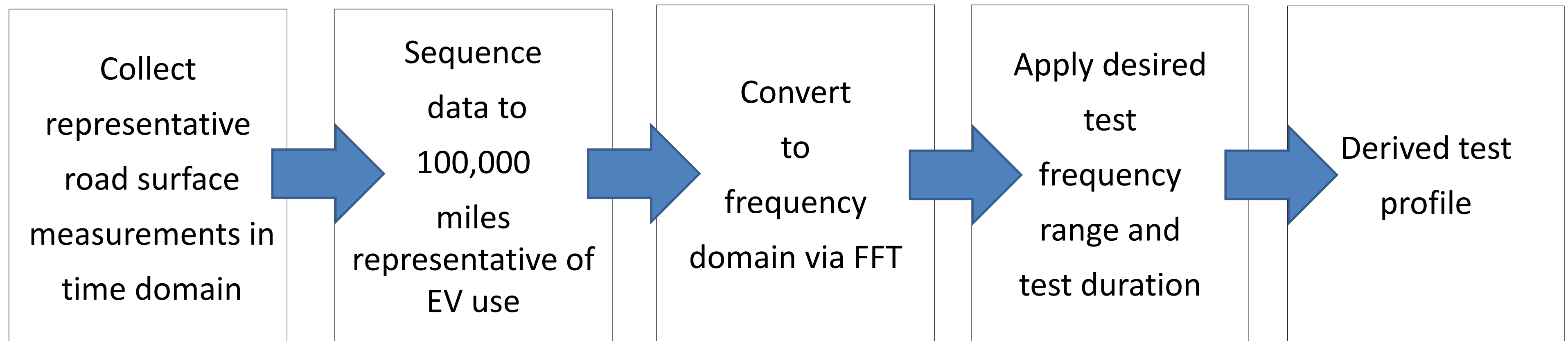
- Millbrook structural durability procedure surface weightings adjusted using EV weighting and sequenced within nCode software:

EV Study Surface Relating to Module	Surface in km	Classification of Surface	Repeats of Surface Required to Simulate 100,000 Miles (160,934km) of BEV weightings	Total Distance in km
Belgian Pave	1.45	Urban	3395	4923
Cats Eyes 30mph	0.16	Rural	5295	847
Cats Eyes 50mph	0.16	Rural	5295	847
City course	1.29	Urban	37177	47958
Handling Circuit	4.51	Rural	1933	8719
Hill route (Loop 1)	1.77	Rural	29695	52560
HSC	5.95	Motorway	2851	16961
Mile Straight (PT)	1.29	Motorway	8141	10502
Mile Straight (WOT)	1.29	Motorway	8141	10502
Pot Holes	0.16	Urban	306	49
Random Waves	0.64	Urban	6791	4346
Sine Wave	0.16	Urban	6813	1090
Twist Humps	0.16	Urban	10186	1630
TOTAL (km)				160934

160934 km = 100,000 miles



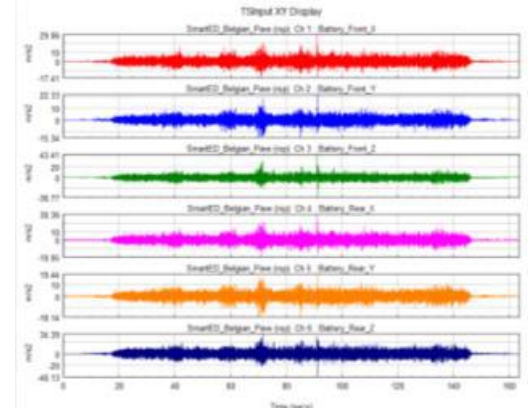
Part 1 - Developing a Representative Random Vibration Profile



Convert to Frequency Domain via FFT

3395
Repeats

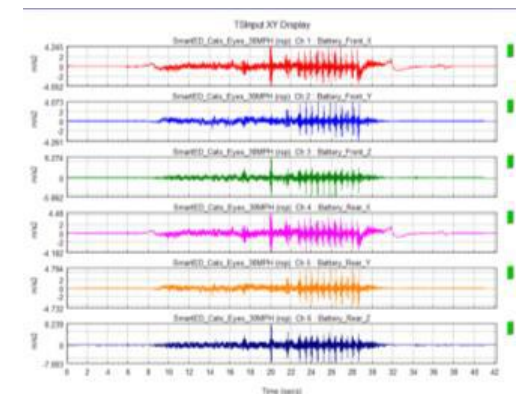
X



+

5295
Repeats

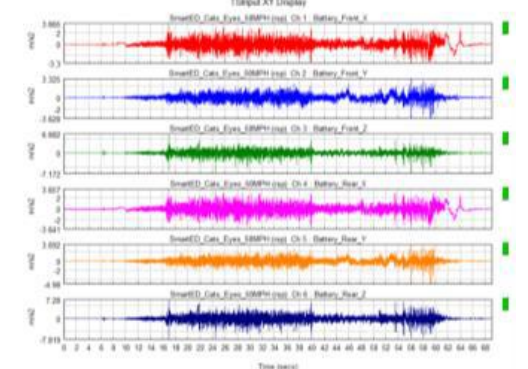
X



+

5295
Repeats

X

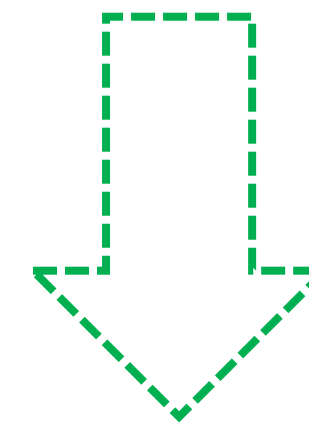


+

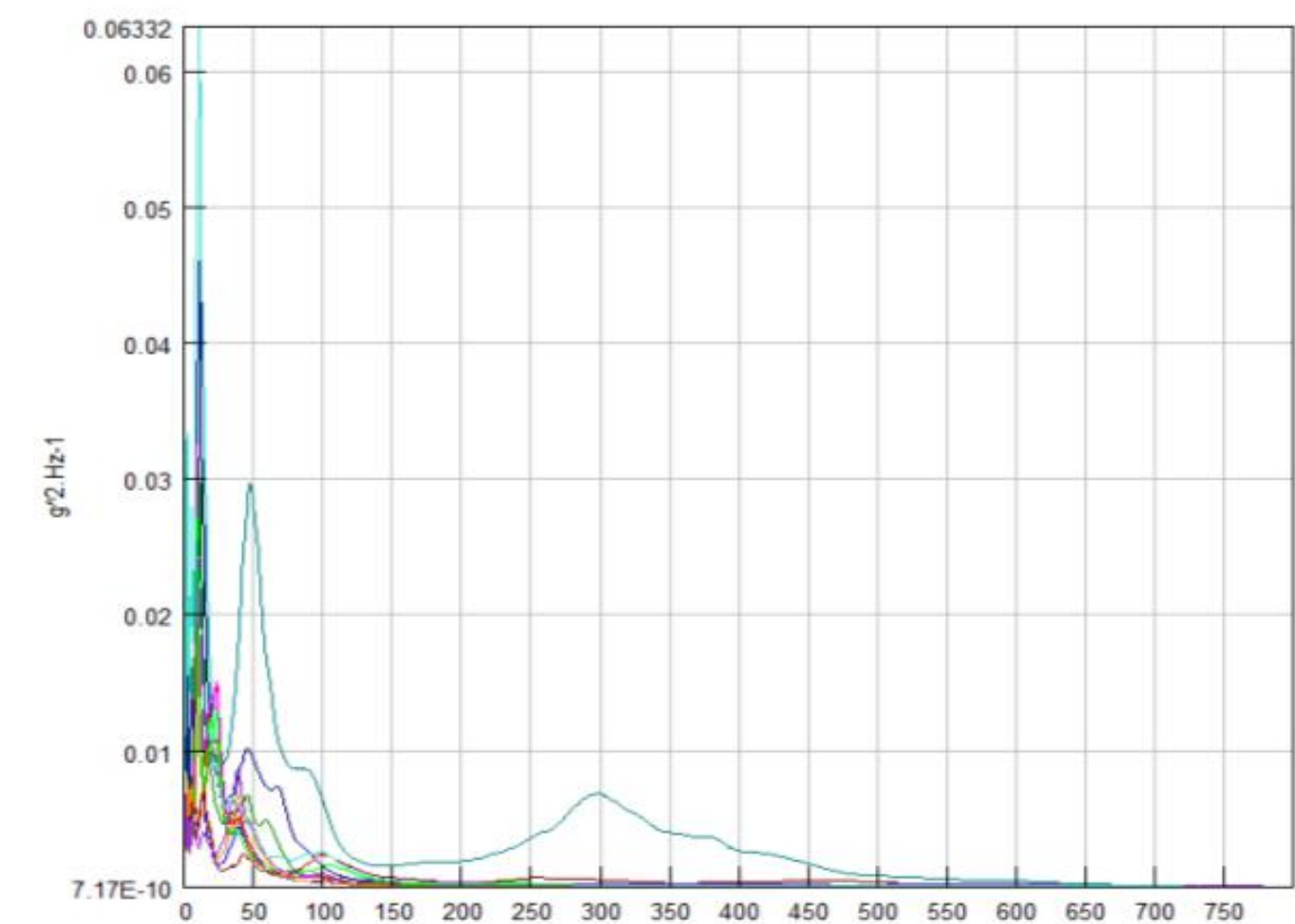
etc.

Application of FFT

$$x_k = \sum_{n=0}^{N-1} x_n e^{-\frac{2\pi i}{N} kn}$$



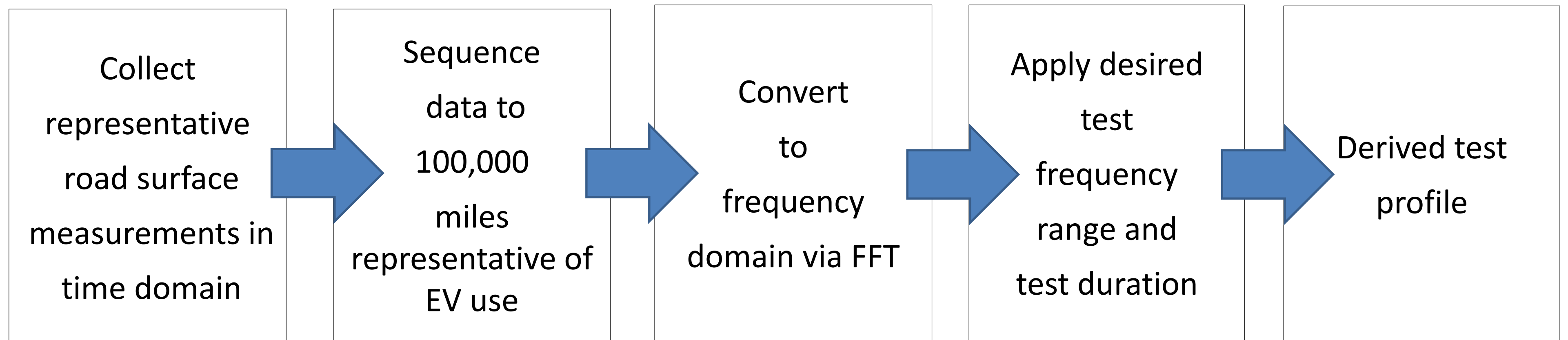
Smart ED



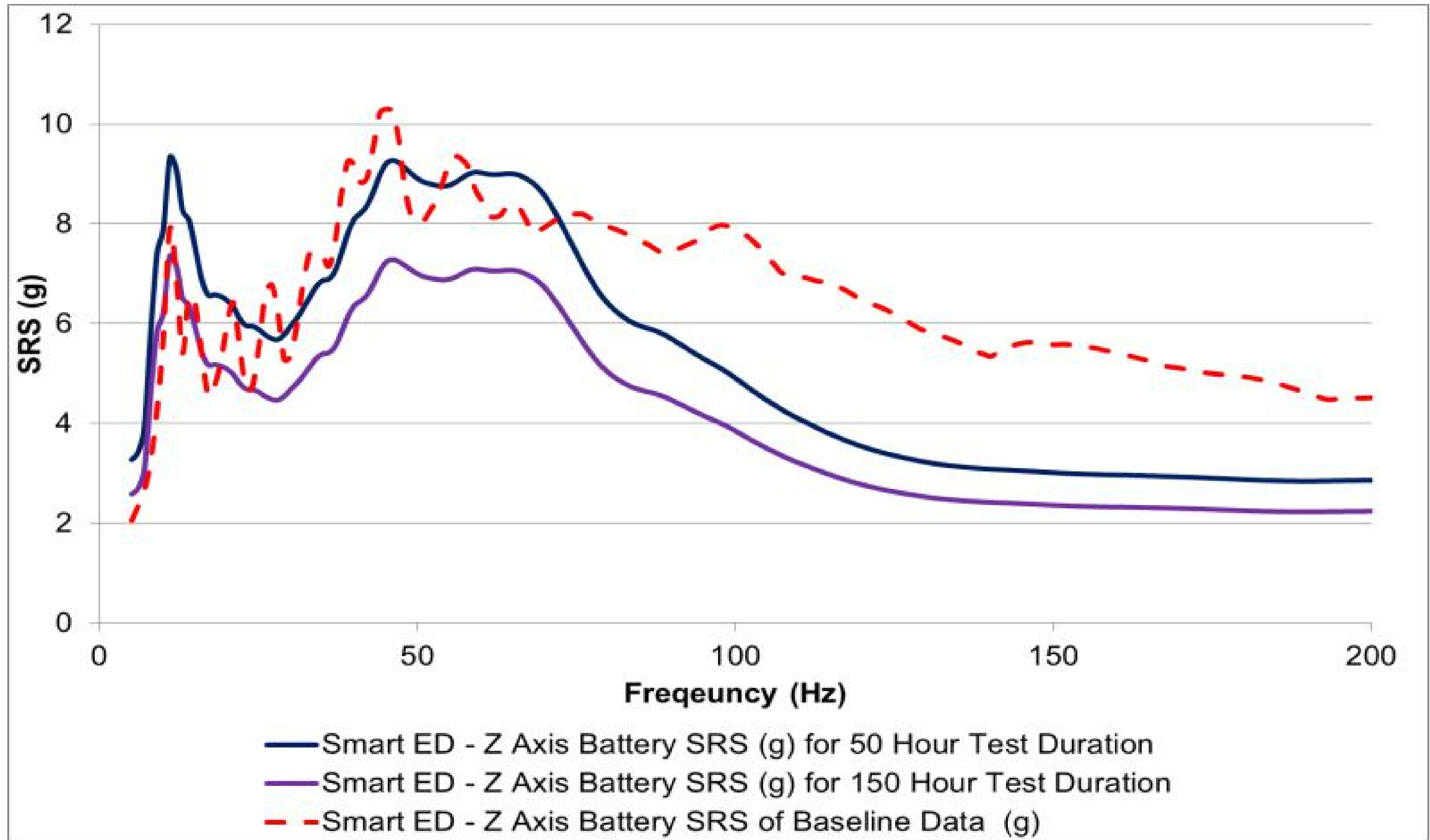
Frequency (Hz)



Part 1 - Developing a Representative Random Vibration Profile



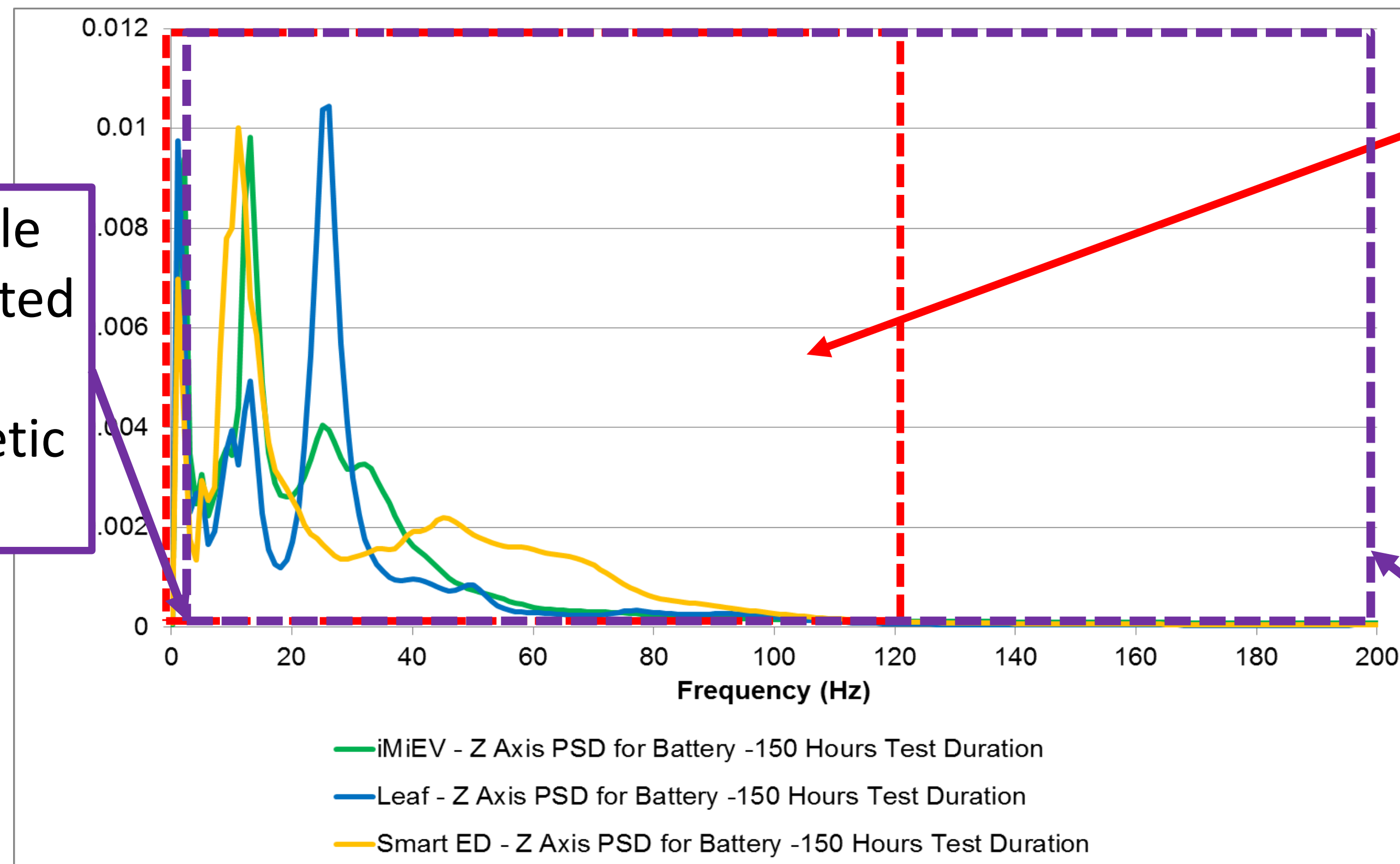
Apply Desired Test Frequency Range and Test Duration



Apply Desired Test Frequency Range and Test Duration

- The frequency range for a random test profile is typically defined by:
 - the frequency band where the peak energy occurs within the measured data.
 - the capabilities of the shaker facilities

5 Hz so profile
can be replicated
on
Electromagnetic
shakers

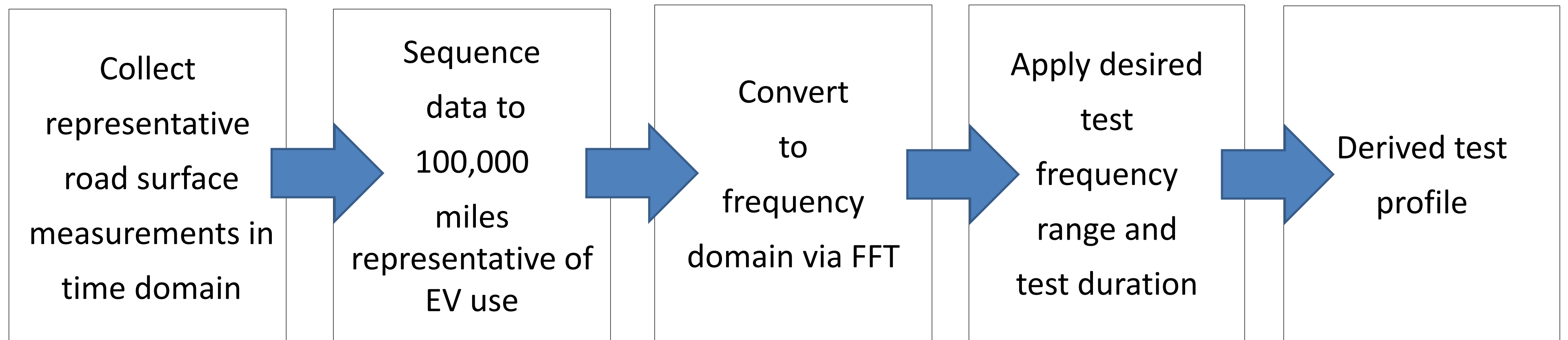


Majority of
acceleration
occurred
between 3
to 120 Hz.

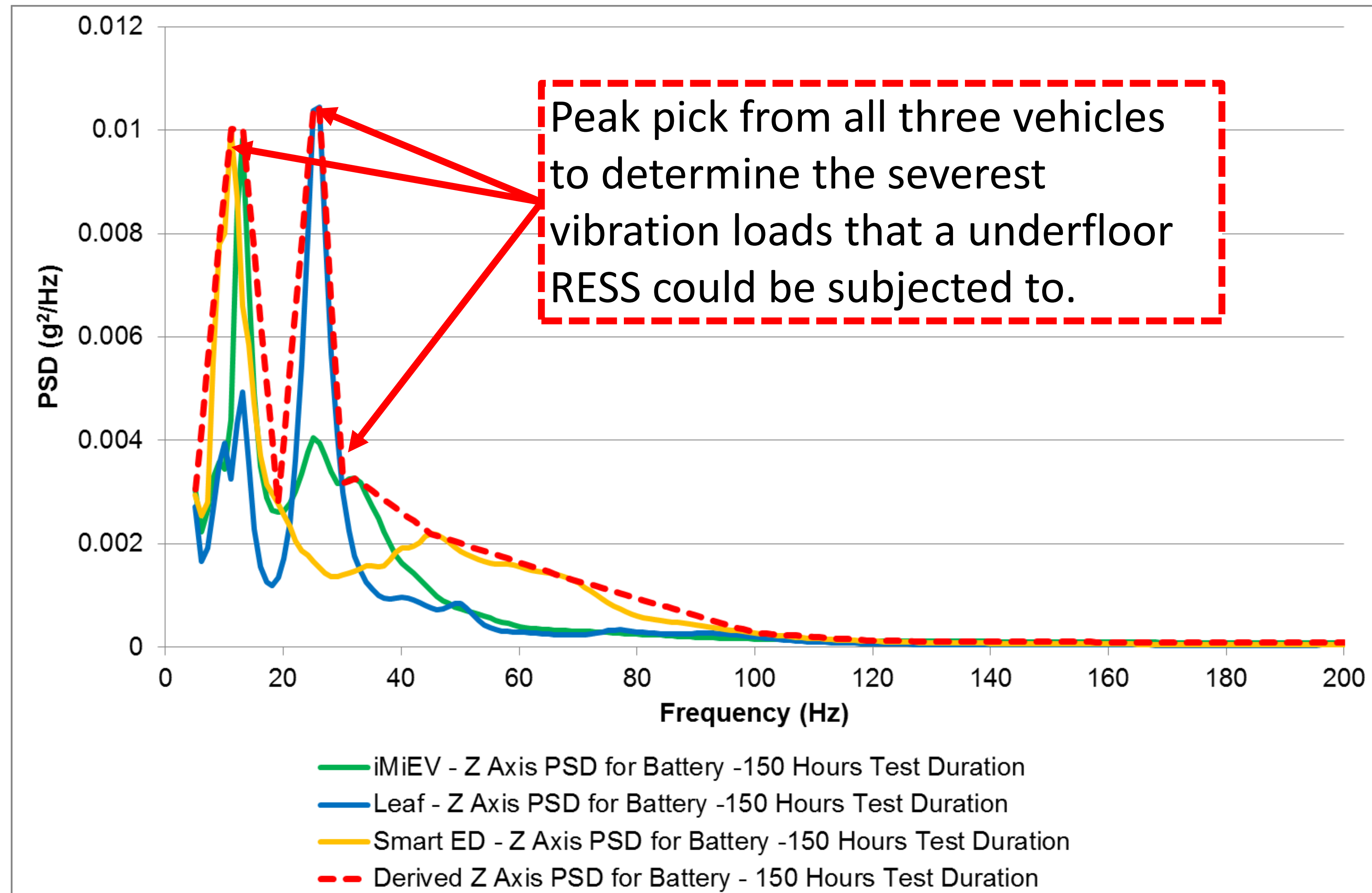
A peak frequency
of 200 Hz was
chosen to ensure
that it could be
replicated on
hydraulic
shakers.



Part 1 - Developing a Representative Random Vibration Profile

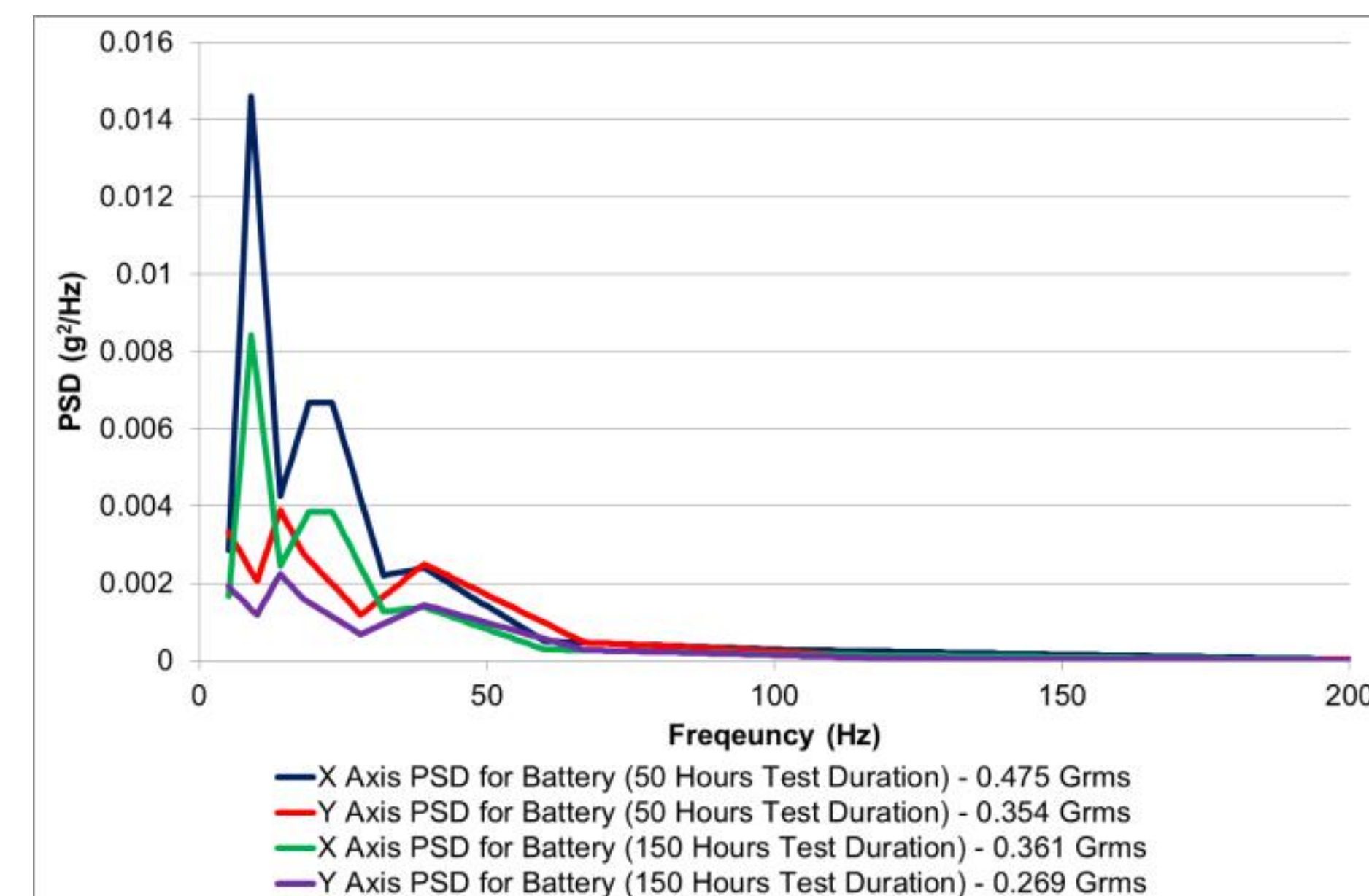
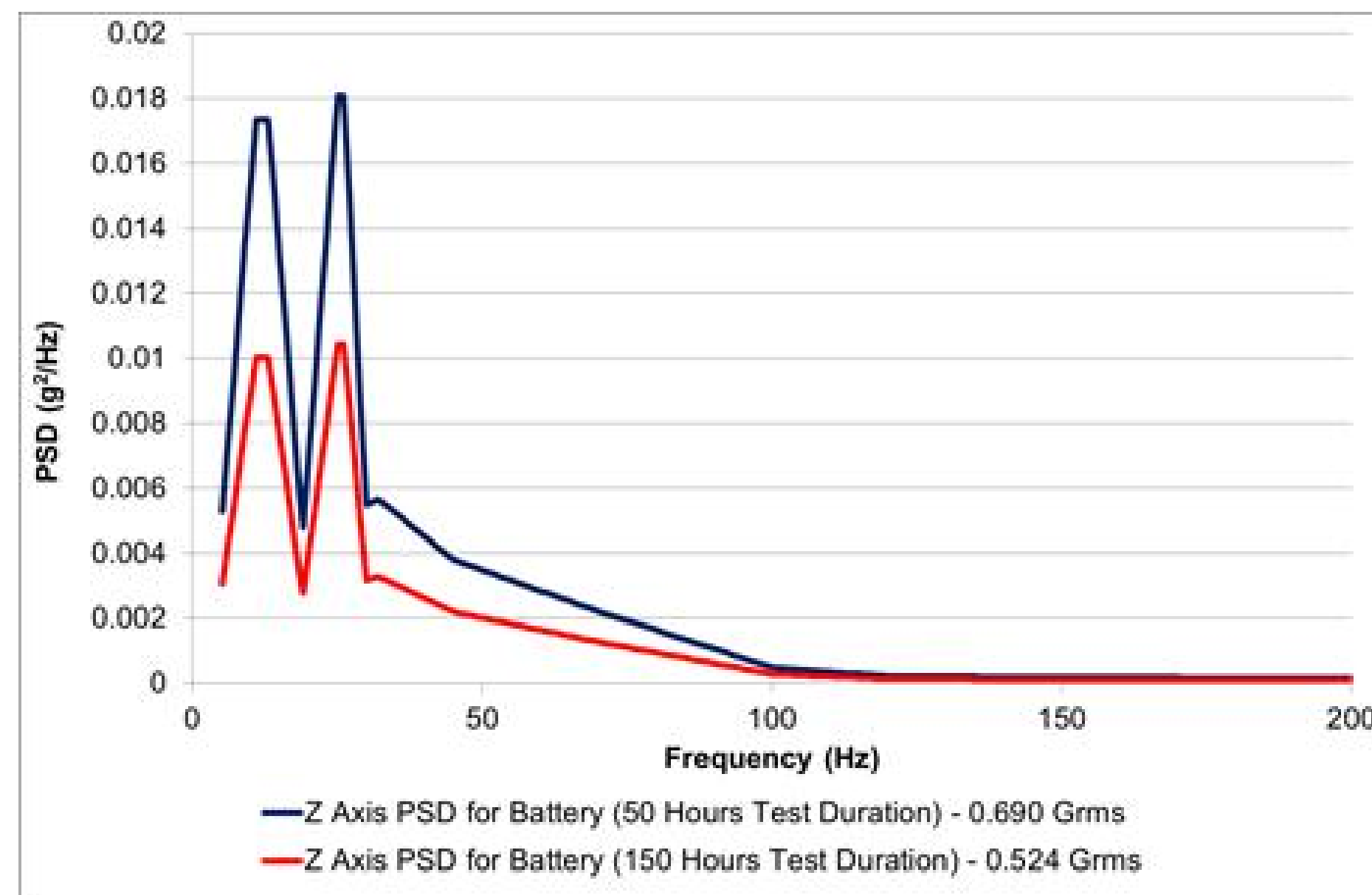


Derived Test Profile

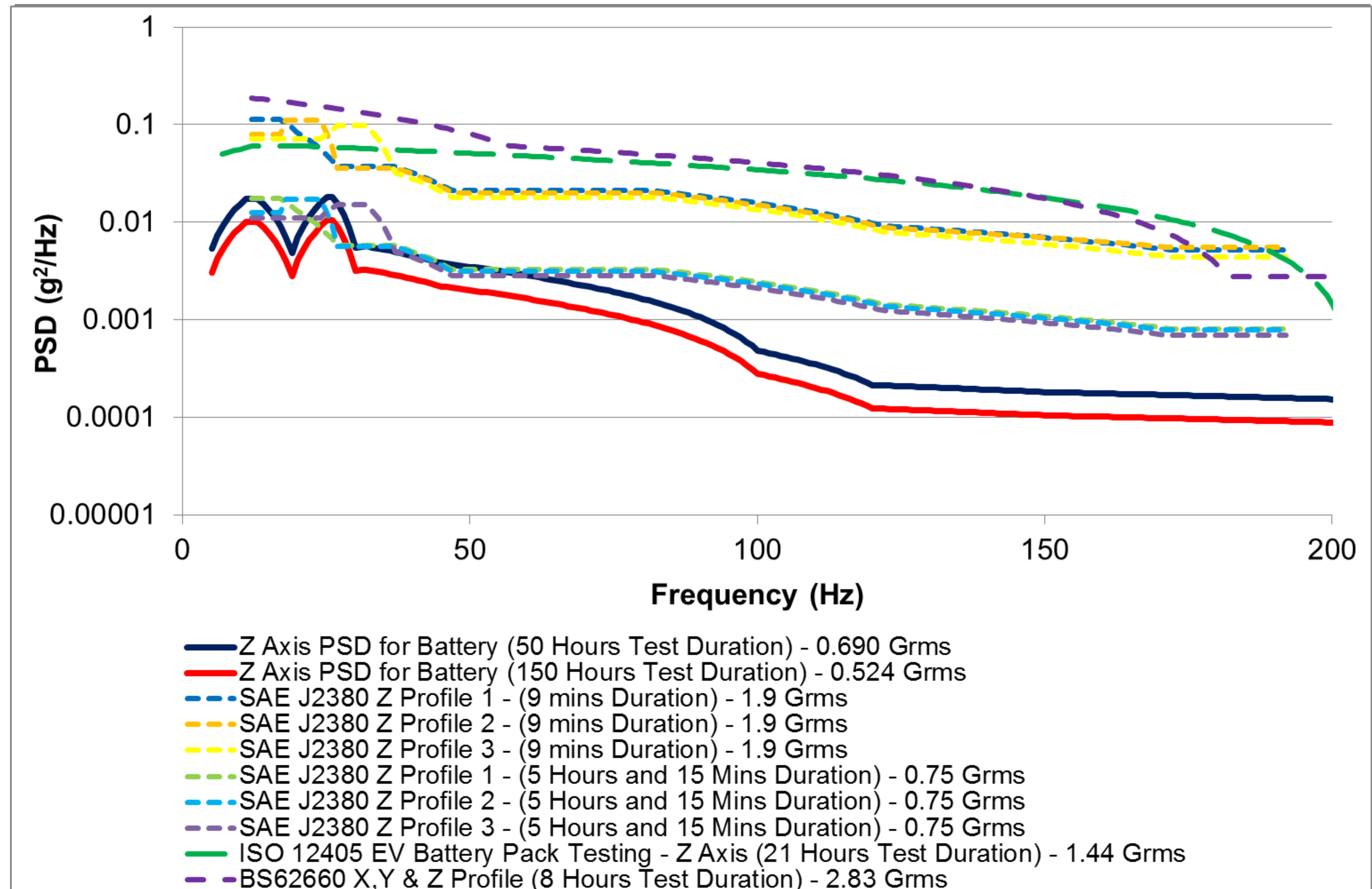




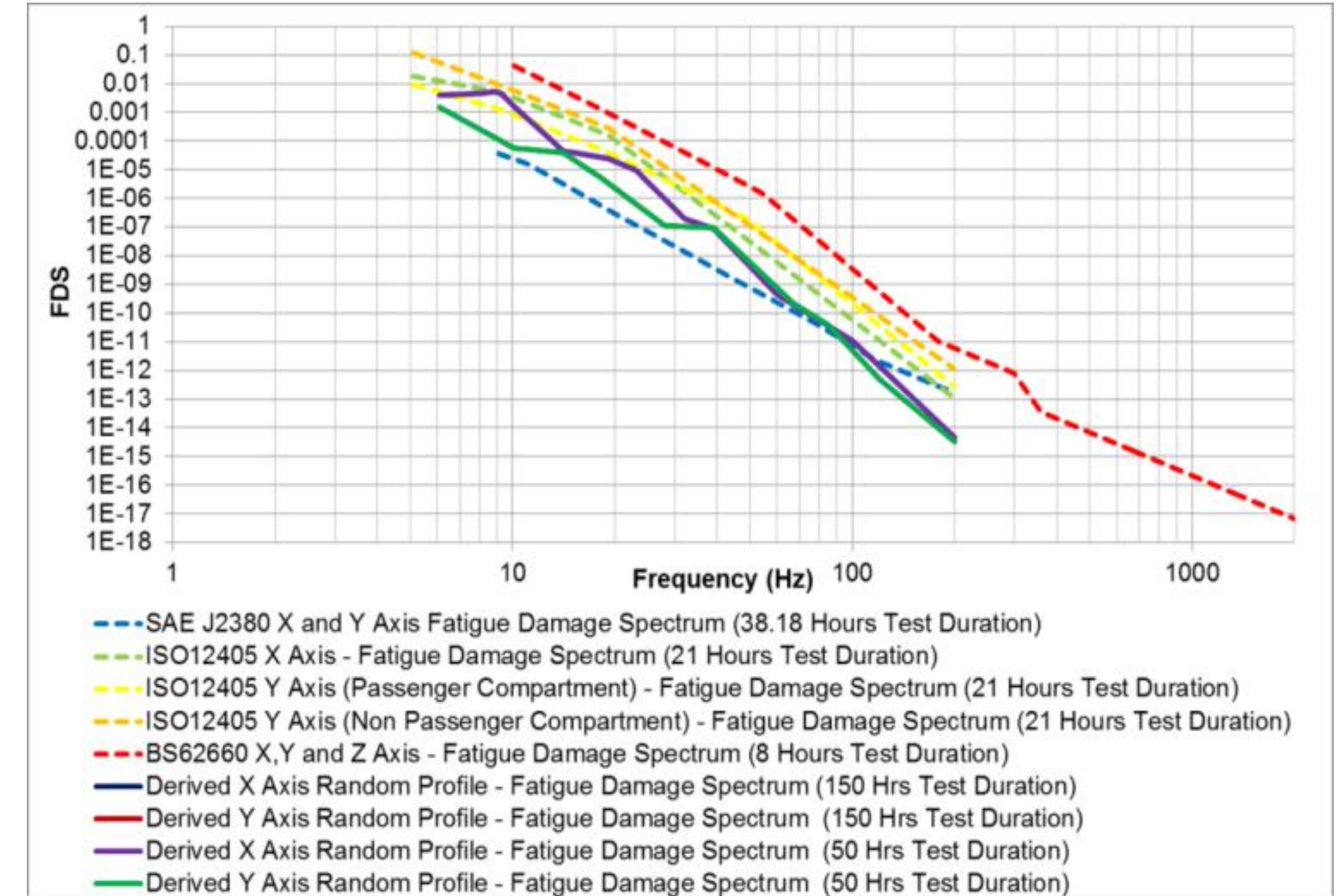
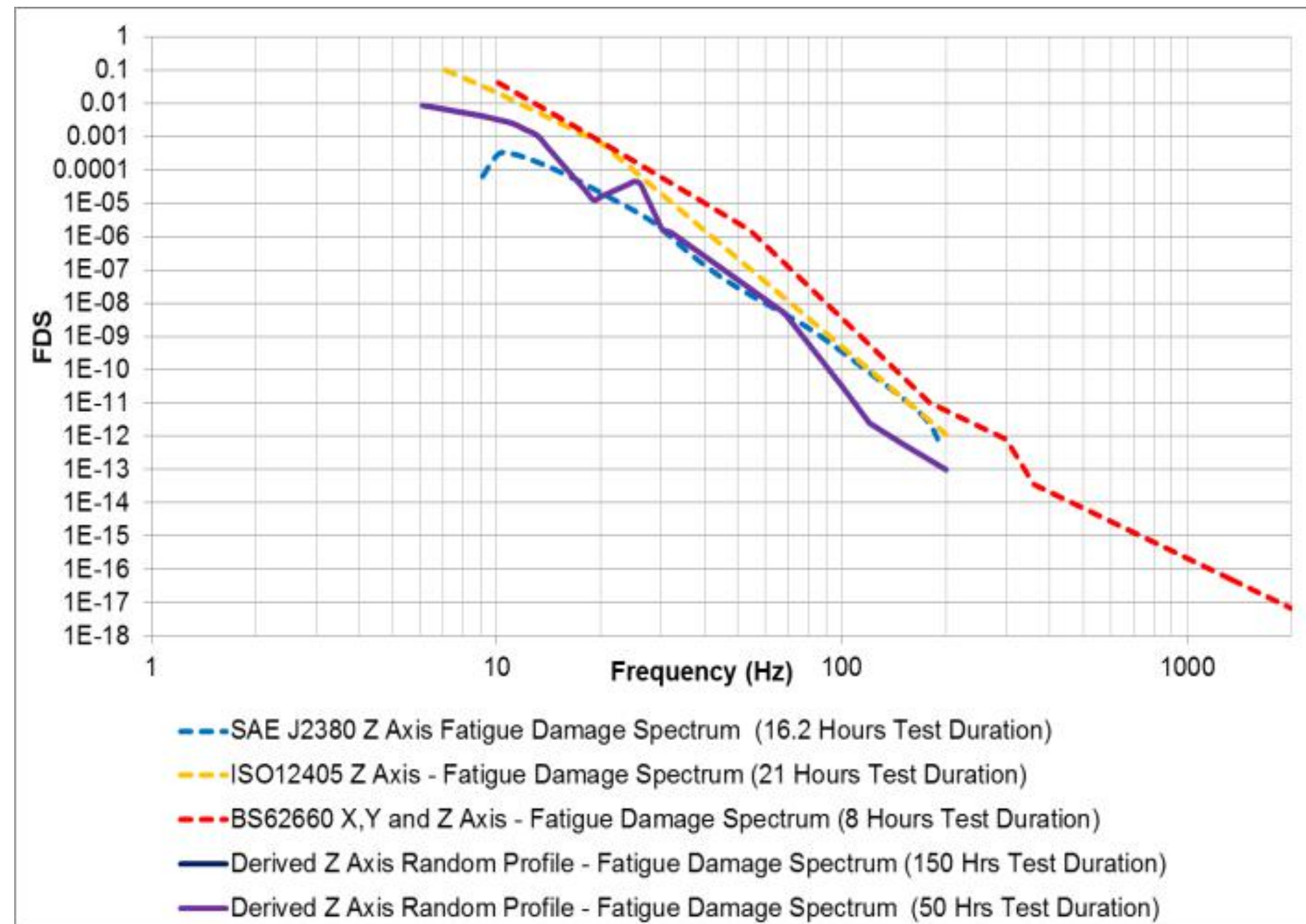
Derived Test Profile



Part 2 – Comparison to Current Standards

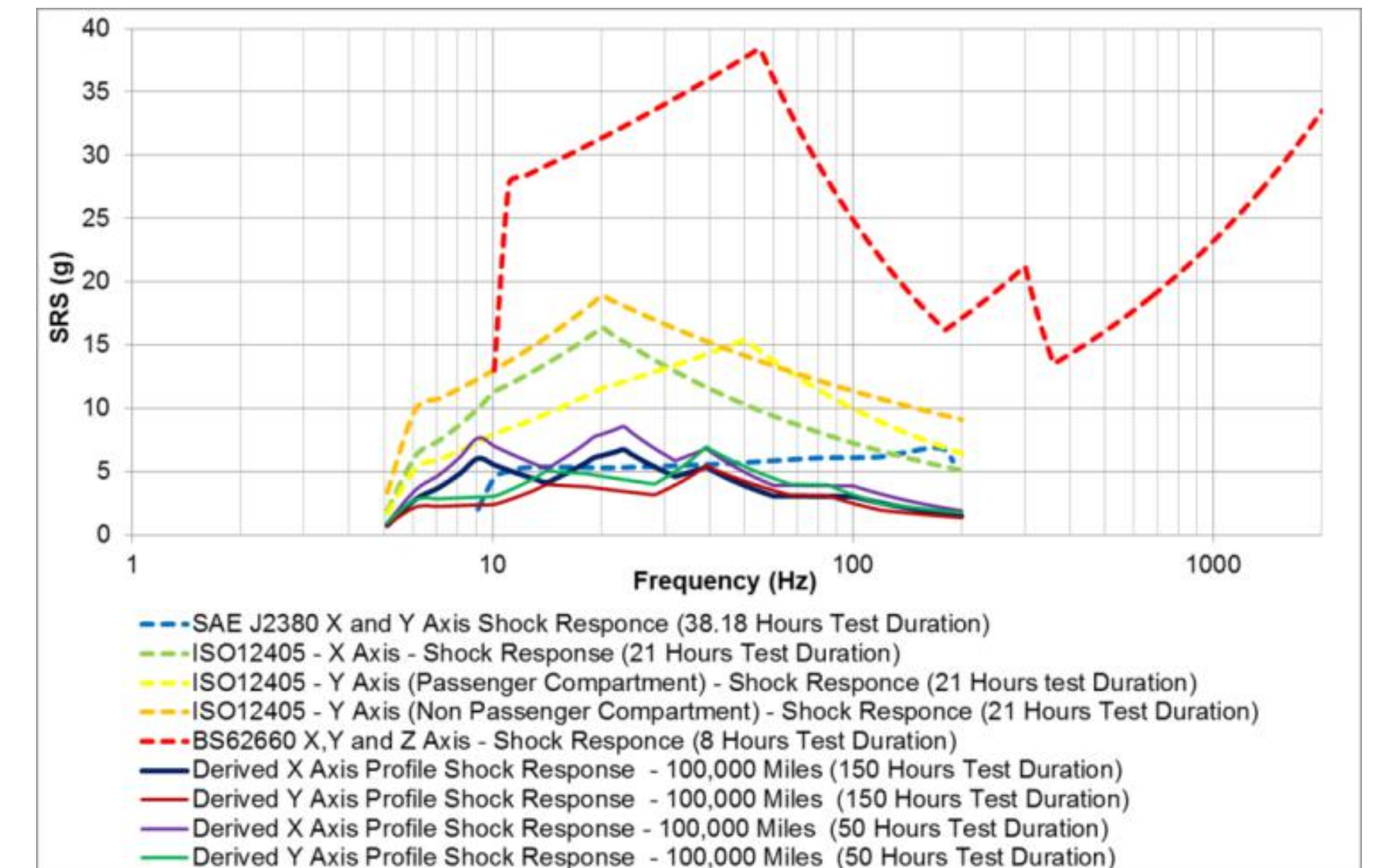
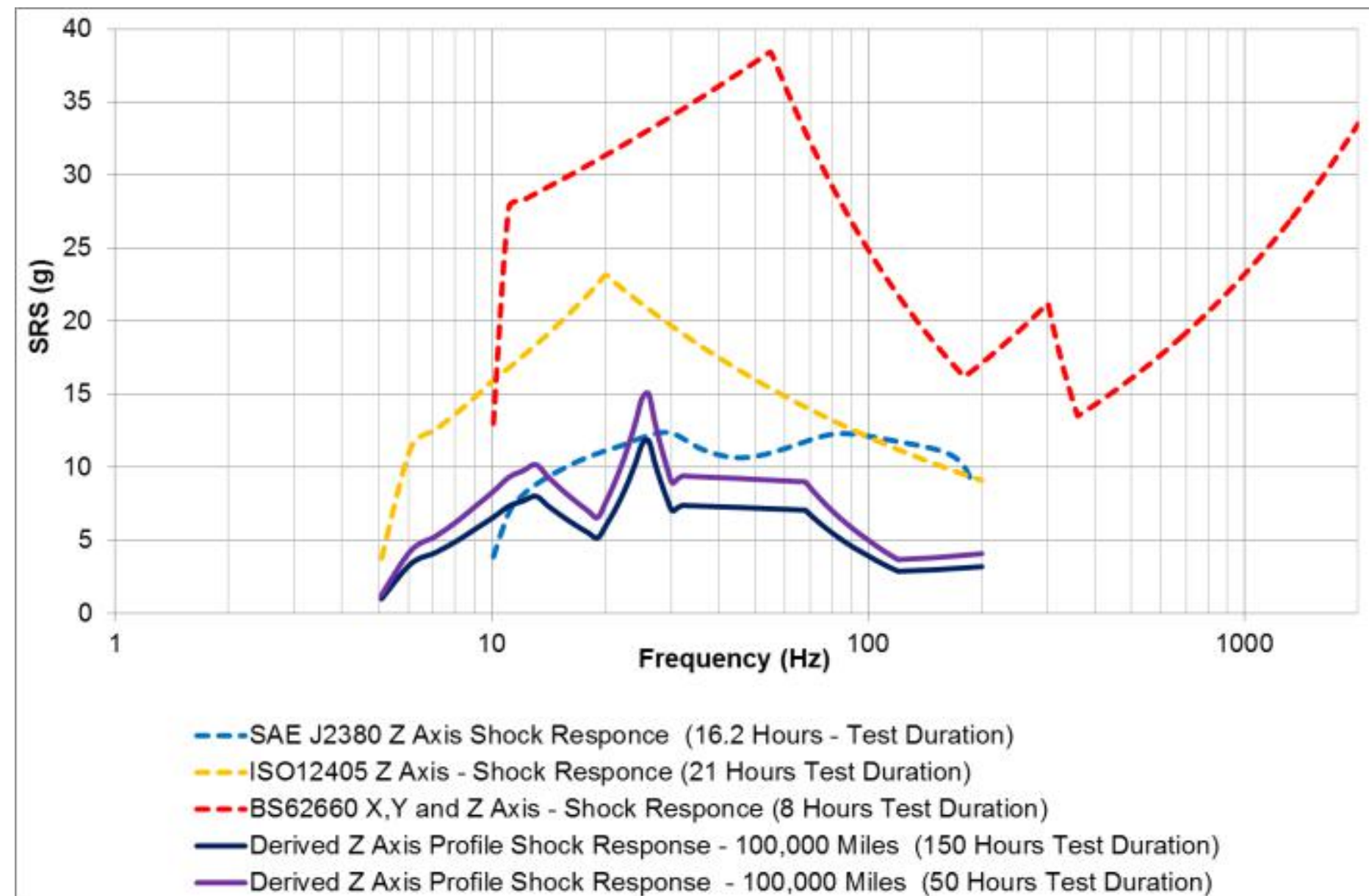


Part 2 – Comparison to Current Standards



- SAEJ2380 and measured data have a comparable fatigue damage from 30 Hz to 70 Hz in Z axis.
- ISO12405 and BS62660 have an unrealistic fatigue loading when compared to measured vehicle data in X, Y and Z axis.

Part 2 – Comparison to Current Standards



- ISO12405 and BS62660 have an unrealistic shock loading when compared to measured vehicle data in X, Y and Z axis
- SAE J2380 has a typically greater shock loading in Z axis, but lower X and Y axis shock loading.



Conclusions

- This study has devised test profiles for testing the X, Y and Z axis of a RESS and its sub components for two different test durations (50 hours and 150 hours per axis) that are representative of 100,000 miles of UK BEV road usage.
- The derived profiles in this study typically have a greater fatigue damage potential with a lower shock loading when compared to SAEJ2380.
- BS62660 and ISO12405 both have significantly greater fatigue damage potential and greater shock loading when compared to EV vibration representative of 100,000 miles of durability.

Questions

- The authors would like to thank:

Dr Andrew Halfpenny, Robert Plaskitt and Mark Embra at HBM nCode for their support with this study.

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All the team at Millbrook Proving Ground Ltd.

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SRS and FDS

- As discussed by Kjell et al: Power Spectral Density (PSD) is mathematically well defined and often used to specify a stationary random vibration test, but it has limitations:
 - Not useful for non stationary vibrations
 - Does not take expose time into account
- Instead of using the PSD, model the test object as SDOF system subjected to the vibration and determine:
- Damage caused by fatigue (mechanical damage) Fatigue Damage Spectrum [cycle counting $z(t)$ + damage law] = FDS
- Damage caused by maximum acceleration Shock Response Spectrum [max of y] = SRS

