Vibrational Analysis for 48V 3.1kWh Battery Pack

Vallepu Bhavana
University Visvesvaraya College of Engineering
Mechanical Engineering

Abstract

In this paper, the Vibrational analysis for 48V 3.1 kWh Battery pack is carried out and has been checked for sustainability under several operational conditions using Ansys. The Battery includes Lithium-ion Pouch cells and PCB and Battery Management System (BMS) which require sustainability and safety during Transportation. The Battery is modeled using CATIA software and file is then imported to ANSYS Software and performed Modal analysis and Random Vibrational Analysis, The Analysis is performed with input parameters such as g-Loads, frequency and acceleration then static Modal and Random Vibrational results are obtained from Ansys are compared

Keywords: -Analysis, Vibration, CATIA, ANSYS, Battery, Modal

I.INTRODUCTION

The 1960s and 1970s saw a need for alternative fueled vehicles to reduce the problems of exhaust emissions from internal combustion engines and to reduce the dependency on imported foreign crude oil. During the years from 1960 to the present, many attempts to produce practical electric vehicles occurred and continue to occur.

The overall impact of the electric vehicle ultimately benefits the people. Compared to gasoline powered vehicles, electric vehicles are ninety-seven percent cleaner, producing no tailpipe emissions that can place particulate matter into the air. Particulate matter, carcinogens released into the atmosphere by gas-powered vehicles, “can increase asthma conditions, as well as irritate respiratory systems”.

The demand for secondary batteries increased rapidly during the past decades and is likely to rise in the future. One cause for this is the sustained demand for portable electronic devices, such as tablets and cellular phones. The progressing electrification of vehicles will further boost the demand for secondary batteries. Lithium-ion batteries play an increasing role for mobile applications where mechanical stress is almost unavoidable. In particular, mechanical vibration and infrequent shock loads affect all parts of a battery including its smallest energy storing part, the accumulator cell, or short cell. Mechanical stress on cell level may cause market durability failures in the long-term and, especially for lithium-ion cells, these failures might pose a safety risk.

The effects of mechanical loads occurring in real-world usage on lithium-ion cells cannot be neglected. Moreover, mechanical tests proposed by standards aim to make only a pass-fail statement. Thereby cell behavior is only classified into failures, which can be seen from outside the cell, e.g., electrolyte leakage, or keeping functionality.

This work aims to provide comprehensive knowledge on how standard vibration and shock tests as well as long-term vibrations affect lithium-ion cells. At the beginning, test standards regarding vibrational and shock loads are listed and compared to real-world load profiles.

Lithium-ion batteries are common batteries in electric and hybrid vehicles. During their lifetime, the batteries will be subjected to vibrations; therefore, vibration testing is demanded by several standards. These standards differ when it comes to frequency range, acceleration levels, etc. From a vibration testing perspective, a battery pack is a complex object built as a large construction containing many small electric compounds. Therefore, the standards might vary depending on the objective of the test. Vibration measurements have been carried out in electric and gasoline vehicles during driving. These measurements are compared with the test severities proposed by the standards. It is found that the vibration test should be performed in three directions and must contain a wide frequency content well above 200 Hz performed during one test or divided into two separate tests. This is not consistent with many of the existing standards today.

Lithium-ion (Li-ion) batteries are widely used today for electrical vehicles (EVs) as they offer high power per kilogram. During their lifetime, the batteries are exposed to environmental stresses that they must sustain and be able to operate at. Therefore, it is crucial to carefully design and environmentally test the batteries for their purpose. Environmental tests are made to state that the design offers a product that does not degrade, will not become a hazard during normal operation and has a long lifetime in relation to its cost.
Safety and reliability studies of electrical failure have naturally gained a lot of focus, but when it comes to safety and reliability owing to environmental stresses such as vibration, temperature and mechanical shock, there is not much research published (Hooper, 2014). There are different reasons for carrying out a vibration test. However, the aim of the test is to give the same fault as
obtained in service. Possible reasons for performing a vibration test are:

1. life simulation test to verify that the test object will have its specified function and
2. performance during its expected lifetime (accelerated test)
3. life simulation test to show that the object will not constitute a danger to persons
4. during its promised lifetime (reliability test)
5. subject the object to short very high stresses to ensure that the object will not pose danger during such events (abuse test).

II.Proposed Methodology

i. Modal Analysis

Model analysis technique is used to determine a structures vibration characteristics-natural frequencies and mode shapes. The study of mode shapes is used as a simple and efficient means of describing resonant vibrations.

The cause for resonant vibration is due to an interaction between the inertial and elastic properties of material within a structure. The vibration related problems that occur in structures and operating machinery are caused due to the resonant effect.

For understanding any structural vibration problem, the resonances of a structure need to be identified and quantified. For this it is required to define the structures modal parameters. The combination of both forced and resonant vibration leads to vibration.

Force vibration can be due to the fact listed below:

– Internally generated forces.

– Unbalances.

– External loads.

– Excitation.

Resonant vibration occurs when one or more of the resonances or natural modes of vibration of a machine or structure is excited by some force. Resonant vibration amplifies the vibration response far beyond the level of deflection, stress and strain than that caused by static loading.

This paper deals with the dynamic behaviour of a rectangular cantilever beam. Modal analysis using ANSYS is explained in simple steps. Mode shapes and frequencies are computed in ANSYS with numerical formulation of the direct solver including the block Lancoz method which is the default method selected by ANSYS. A simple formula for computation of the fundamental natural frequency of a cantilever beam vibration under certain boundary condition and loading are presented. The formulas presented in this paper are quite simple and the fundamental frequency could be obtained by hand calculation with an estimated error.

MODAL ANALYSIS WITH ANSYS

Engineers need to understand the physical behavior of complex object. They also need to predict the dynamic behavior, performance, calculate the safety margin and accurately identify opportunities for improvement in the design phase. Thus, by use of ANSYS this goal can be achieved in less time and at lower cost than with traditional prototyping. The steps for modal analysis using are given below:

– Geometric model

– Finite Element model

– Boundary Condition

– Mesh of Finite Elements

– Modal Analysis

A. Geometric Model:

The component is generated as 3D CAD model considering the design dimensions and working clearances as per the given data.

B. Finite Element Model:

The model created using Creo 2.0 was imported in Ansys. Some simplification is necessary to keep the model from becoming too large to solve, but it is also reasonable to neglect small geometric details that have little impact on the component rigidity.

C. Boundary Conditions:

The material properties are assigned to the model and boundary conditions are defined.

D. Mesh of finite elements:

For better approximation of the solution many elements are provided, but in some cases a greater number of elements may increase the error and solving time. Therefore, mesh should be adequately fine or coarse in the appropriate regions. Different techniques are used for mesh refinement like i) Adaptive Meshing, ii) Mesh Refinement Test within ANSYS, iii) Sub modeling.

E. Modal Analysis:

The natural frequencies are extracted using the direct solver which uses the block Lanczos method in ANSYS.

ii. Random Vibration analysis

- A Random Vibration Analysis is a form of Spectrum Analysis. It is used to calculate the response due to non-deterministic loads. Examples of non-deterministic loads include:

  a. Loads generated on a wheel of a car travelling on a rough road

  b. Base accelerations generated by earthquakes

  c. Pressure generated by air turbulence

  d. Pressure from sea waves or strong wind

- The spectrum is a graph of spectral value versus frequency that captures the intensity and frequency content of time-history loads.
- Random vibration analysis is probabilistic in nature, because both input and output quantities represent only the probability that they take on certain values.
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PSD Spectrum:

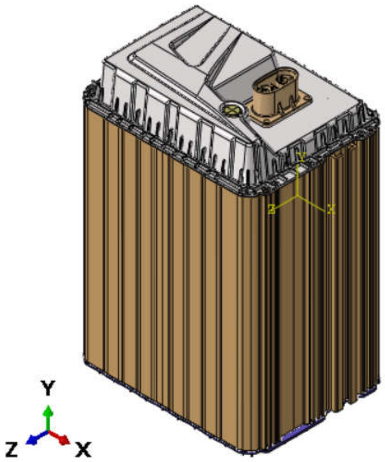
- A PSD spectrum is a statistical measure of the response of a structure to random dynamic loading conditions. It is a graph of the PSD value versus frequency, where the PSD may be a displacement PSD, velocity PSD, acceleration PSD, or force PSD. Mathematically, the area under a PSD-versus-frequency curve is equal to the variance (square of the standard deviation of the response).

III. Experiment and Result

1. Modal Analysis

Like solving any problem analytically, we need to define (1) solution domain, (2) the physical model, (3) boundary conditions and (4) the physical properties and then solve the problem and present the results. In numerical methods, the main difference is an extra step called mesh generation. This is the step that divides the complex model into small elements that become solvable in an otherwise too complex situation. Below describes the processes.

Here we have taken 48V 3.1KWH Battery for analysis.



Assumptions:

Isotropic material properties are considered

There will be no relative displacement between components during the modal simulation.

Preassembly conditions (ex: sealing interference, fasteners preload and pouch cell tab bending) are not considered for the analysis.

Modal damping of 3% is considered for random simulations.

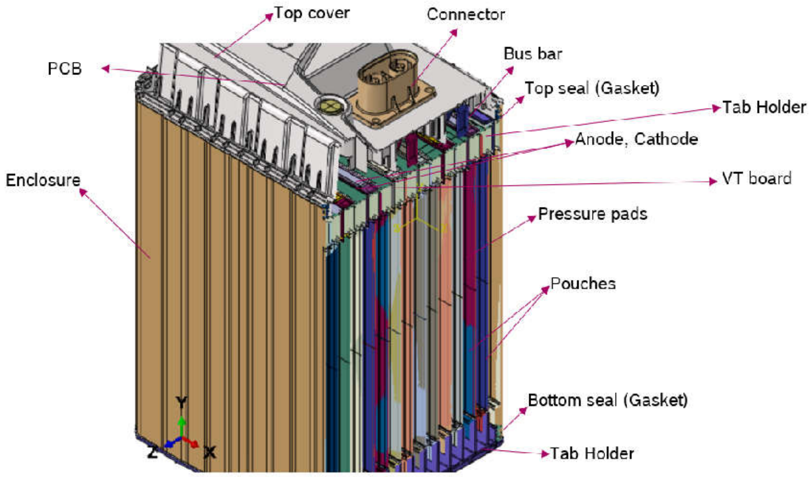
Total mass of the assembly considered for simulation is 23.17kg.

Accuracy:

The natural frequency obtained are qualitative for the given Boundary condition and material properties.

Below describes the processes

Build Geometry: Construct a two- or three-dimensional representation of the object to be modelled and tested using the work plane coordinate system within ANSYS.

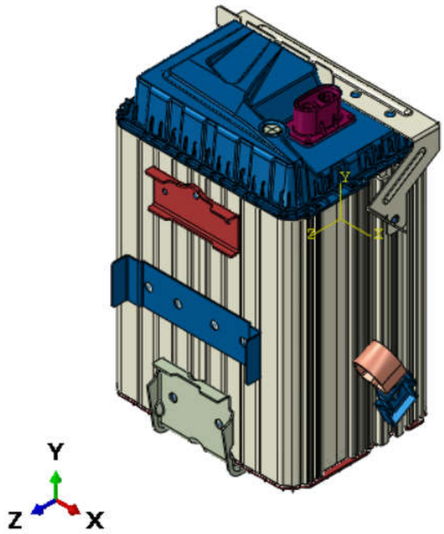


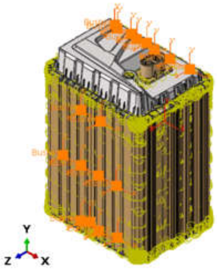
Define Material Properties: Now that the part exists, define a library of the necessary materials that compose the object (or project) being modeled. This includes thermal and mechanical properties.

Material name	Part	Density [gm/cm^3]	E-modulus [MPa]			Poisson's Ratio		
EN AW-6012 Aluminum wrought alloy	Al Enclosure, Anode	2.75	68900			0.33		
PA6GF30 Ultramid® B3WG6 BK00564	Tab holder, top &bottom cover, Top plug, VT board connector	1.36	6000			0.39		
PA6GF30 Ultramid® B3WG6 BK00564	Top plastic cover and output connector	1.36	6000			0.39		
Copper DIN EN 13599	Buss bar, Cathode	8.96	110000			0.3		
Softer than aluminum	Pouches	2.15	50000			0.3		
Norseal PF27	Compression pads	0.25	15			0.25		
FR4	VT board and PCB	1.17	31066	31066	14680	0.2	0.3	0.3
TPE-TC6PCN THERMOLAST Elastomer	Gasket [Seal]	1.1	C10 0.500906	D1 0.001				

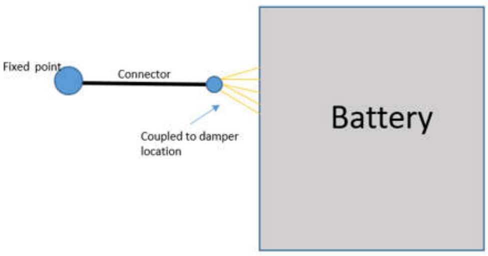
Generate Mesh: At this point ANSYS understands the makeup of the part. Now define how the modelled system should be broken down into finite pieces.

Apply Loads: Once the system is fully designed, the last task is to burden the system with constraints, such as physical loadings or boundary conditions.





The end points of the connectors are fixed



Representing damper as connector

Connector stiffness

- The stiffness of connector is assigned as below w.r.t to frequency.
- The units of stiffness are in N/mm
- Standard stiffness values of elastomer with shore hardness 50A-70A is taken

Obtain Solution: This is actually a step, because ANSYS needs to understand within what state (steady state, transient… etc.) the problem must be solved.

Modes	Frequency(Hz)
Mode 1	576.17
Mode 2	854.92
Mode 3	927.16
Mode 4	1097.6
Mode 5	1153.9
Mode 6	1411
Mode 7	1518
Mode 8	1613.1
Mode 9	1729.2
Mode 10	1965.7

Present the Results: After the solution has been obtained, there are many ways to present ANSYS' results, choose from many options such as tables, graphs, and contour plots.

2. Random Vibrational Analysis

In a random vibration study, loads are described statistically by power spectral density (psd) functions. The units of psd are the units of the load squared over frequency as a function of frequency. For example, the units of a psd curve for pressure are (psi)2 / Hz over Hz.

- Test profile (Z axis 21hours -> X axis 21hours -> Y axis 21 hours)

Z direction profile

	Z
Hz	PSD(g^2/Hz)
30	0.054
75	0.054
190	0.003
520	0.003
800	0.0016
1000	0.0015
2000	0.001

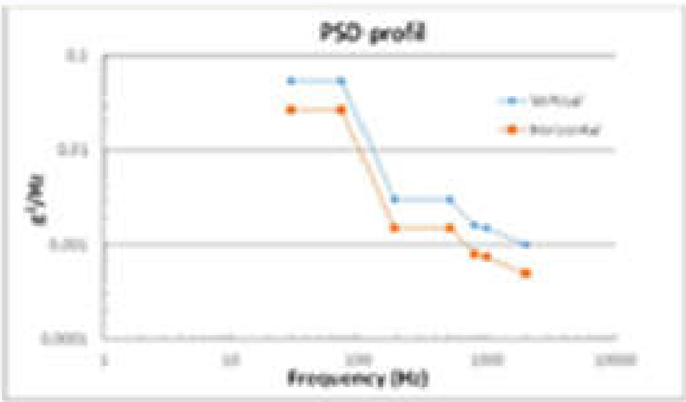
X&Y direction profile

	X,Y
Hz	PSD(g^2/Hz)
30	0.027
75	0.027
190	0.0015
520	0.0015
800	0.0008
1000	0.00075
2000	0.0005

- Test temperature (follow the range as per the product specs)

Temperature (DegC)	Time (minutes)
20	0
-20	60
-20	150
20	210
60	300
60	180
20	480

The psd curve is shown below. The X axis (frequency Hz) is plotted on a logarithmic scale for a clear illustration of the wide frequency range. The unit for Y-axis is amplitude2/ frequency.

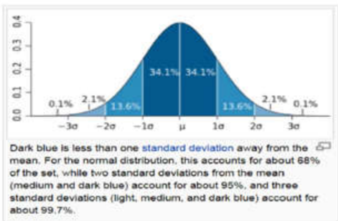


The solution of random vibration problems is formulated in the frequency domain

After running the study, you can plot root-mean-square (RMS) values, or psd results of stresses, displacements, velocities, etc. at a specific frequency or graph results at specific locations versus frequency values.

A root-mean-square (RMS) formulation translates the PSD curve for each response quantity into a single, most likely value. Because PSD curves represent the continuous probability density function of each response measure, most of the integrated area will occur near the resonant frequencies of the structure.

Statistics are required to assess the probability of the response's magnitude



Dark blue is less than one standard deviation away from the mean. For the normal distribution, this accounts for about 68% of the set, while two standard deviations from the mean (medium and dark blue) account for about 95%, and three standard deviations (light, medium, and dark blue) account for about 99.7%.

- Random theory assumes that the input follows a Gaussian distribution.
- The same assumption applies to the response

$$p(x) = \frac{1}{\sigma\sqrt{2\pi}} e^{\frac{-x^2}{2\sigma^2}}$$

	X	Y	Z	% Of Occurrence
1 σ	0.27	0.408	1.428	68%
2 σ	0.38	0.57	1.995	95%
3 σ	0.398	0.598	2.0937	99.7%

IV. CONCLUTION

- ✓ It has been observed that Max stress in Z-direction occurred at PCB a Max of 2.1 Psi.
- ✓ In X and Y-direction Max stress occurred at Tabs Bending.
- ✓ The deformations that are performed on Battery by providing number of Mode shapes as Ten, in which we got first result as 576.17 Hz and tenth natural frequency as 1965.7 Hz.
- ✓ In the Experimental analysis it has been observed the end Lithium-ion pouch cells are getting hot because of friction with wall surfaces.
- ✓ Random Vibrational analysis is performed for the entire battery part with the frequency range between first and tenth Modal shapes which shows responses at different frequencies.

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