RELIABILITY CALCULATION AND HIGHLY ACCELERATED LIFE TEST (HALT) OF BATTERY MANAGEMENT SYSTEM PRINTED CIRCUIT BOARD ASSEMBLY (PCBA) USING SHERLOCK SOFTWARE

TECHNICAL FIELD

[0001] The present invention relates to a method and system for reliability calculation of a printed circuit board assembly. More specifically, the present invention relates to a method and system for reliability calculation of a printed circuit board assembly for a battery management system.

BACKGROUND OF THE INVENTION

[0002] Background description includes information that may be useful in understanding the present invention. It is not an admission that any of the information provided herein is prior art or relevant to the presently claimed invention or that any publication specifically or implicitly referenced is prior art.

[0003] A Battery Management System (BMS) is an electronic system that oversees and regulates the charging and discharging of rechargeable batteries, ensuring their safe and efficient operation. It plays a crucial role in monitoring battery parameters, protecting against potential hazards, and optimizing performance. Battery Management Systems are integral to various applications, including Electric Vehicles (EVs), renewable energy storage, consumer electronics, Uninterruptible Power Supplies (UPS) etc.

[0004] EVs are becoming an increasingly popular segment of the automobile industry across the world, and electric two-wheeler contributes massively to the popularity of electric vehicles due to the many benefits and advantages provided. These EVs, invariably comprise of a series of batteries connected together in a battery pack to generate required power output. Due to arrangement of large of number interconnected batteries in a compact space in an EV, a BMS is required for proper and safe functioning of the power supply system. The primary function of the BMS include in an EV includes battery parameter detection, battery state estimation, online failure diagnosis, battery safety control and alarm, charging control, battery equalization, thermal management, network communication and information storage.

[0005] The BMS includes a plurality of sensors, an actuator, a controller, a signal cable, arranged on a Printed Circuit Board Assembly (PCBA). As a carrier of various components and a hub for circuit signal transmission, PCBA may be considered as the most important and

critical part of the BMS. The quality and reliability of the PCBA determines the quality and reliability of the entire BMS. However, due to cost and technical reasons, it becomes difficult to determine the quality and reliability of the PCBA resulting in failures during production and/ or application of the PCBAs of the BMS.

[0006] **Fig. 1** illustrates a Bathtub Reliability Curve **100**, as per the Military Hand Book Standard. As illustrated, Fig. 1 refers to graphical representation of the reliability curve obtained mathematically (solid line) and the one predicted, as per standard (Dotted Line). It can be seen from the graph that the methodology of predicting reliability based on standards and previous field data cannot give complete insights due to the rapid development and complexity in the electronics. Moreover, the traditional method assumes the total failure rate as constant across the product life which is not practical. The failure rate during the start of the process, which includes manufacturing, design and end of life components like wear and tear of components are not duly accounted.

[0007] The Bathtub Reliability Curve **100**, as referred in **Fig. 1**, based upon statistical approach assumes a single scenario i.e., failures at start and at end. The disadvantages of the statistical approach are as follows:

- Standards are not being updated frequently;
- Validation of calculations and standards are not being performed by any literatures;
- As per standard, the calculations are performed solely considering single hot spot temperature and a fixed environment, as per Military standard;
- Base failure rates most of the electronics are based on field failures data but the effect of failure is not captured and improvements made in each component is not accounted in the data;
- Calculations do not capture the real time conditions of temperature and vibrations;
- Moreover, the mathematical calculations consider all component are connected in series and do not capture the redundancy of the system.

[0008] The methodologies disclosed in state of art for reliability calculation of the PCBA used various statistical methods to predict failure rate and the Mean time between failures (MTBF) calculation. MTBF is the predicted elapsed time between inherent failures of a mechanical or electronic system during normal system operation. The existing

methodologies are not only time consuming and inaccurate but also require a complex lab testing procedure which increase the overall cost of the procedure.

[0009] Hence, there arises a need for a method and system that provides reliability calculation and prediction of life of the BMS PCBA in an improved and efficient manner, thereby addressing the abovementioned problems.

OBJECTIVE OF THE INVENTION

[00010] A general objective of the present invention is to provide a method and a system for reliability calculation of a Printed Circuit Board Assembly (PCBA) of a Battery Management System (BMS) that provides precise prediction about failure;

[00011] Another objective of the present invention is to reduce failure instances during manufacturing of the BMS PCBA.

[00012] Another objective of the present invention is to provide a reliability calculation method for the BMS PCBA in a cost-effective manner.

[00013] Still another objective of the present invention is to provide an improved reliability calculation method for the BMS PCBA that provides result in reduced time.

SUMMARY OF THE INVENTION

[00014] The summary is provided to introduce aspects related to an improved reliability calculation method and system for a Printed Circuit Board Assembly (PCBA) of a Battery Management System (BMS), and the aspects are further described below in the detailed description. This summary is not intended to identify essential features of the claimed subject matter nor is it intended for use in determining or limiting the scope of the claimed subject matter.

[00015] In one aspect of the invention, a method for reliability calculation of a Printed Circuit Board Assembly (PCBA) is provided. The method comprises configuring an algorithm to perform High Accelerating Life Testing (HALT) of a plurality of components located on the PCBA in a simulating environment. The algorithm comprises of steps: providing PCBA layout information so as to draw virtual pattern of the plurality of components; determining sequence of a plurality of testing parameters; setting a targeted failure rate; monitoring performance and obtaining data for each of the plurality of testing parameters; analyzing data so as to predict failure rate of the PCBA, accurately.

[00016] According to an embodiment of the invention, the plurality of testing parameters comprises: Solder Fatigue Analysis; Thermal Derating Analysis; Thermal Mechanical Analysis; Vibrational Analysis.

[00017] According to an embodiment of the invention, the algorithm provides a reliability score for each of the plurality of components located on the PCBA.

[00018] According to an embodiment of the invention, the algorithm provides a board-level PCBA design with high reliability score.

[00019] In yet another embodiment of the invention, the algorithm provides a physical map for weak reliability points on the PCBA.

[00020] In an embodiment of the present invention, the algorithm is configured to detect deviation of performance of the plurality of components located on the PCBA from standard data.

[00021] According to an embodiment of the invention, the algorithm provides design recommendation to an operator for increasing reliability of the PCBA.

[00022] In yet another embodiment of the invention, the PCBA is for a Battery Management System (BMS) of an electric vehicle

[00023] In one aspect of the invention, a system is provided for reliability calculation of the PCBA, wherein the system comprises: a processor, a memory and a plurality of sensors to perform the HALT of the plurality of components located on the PCBA of the BMS in a simulating environment.

[00024] According to an embodiment of the invention, the processor implements a plurality of modules, the module comprises: Solder Fatigue Analysis Module; Thermal Derating Analysis Module; Thermal Mechanical Analysis Module; Vibrational Analysis Module.

[00025] The method and system for reliability calculation of the Printed Circuit Board Assembly (PCBA) offers an advantage over the state of art as it ensures that the prediction about failure is accurate so as to reduce failure instances during manufacturing of the BMS PCBA. The method provides that a High Accelerating Life Testing (HALT) is performed using an algorithm in simulated environment. The processor implements different for analysis module comprising Solder Fatigue Analysis; Thermal Derating Analysis; Thermal Mechanical Analysis; Vibrational Analysis. The method consolidates data provided by

different analysis module to provide accurate failure prediction of the BMS PCBA in a reduced time.

[00026] Other objects, features and advantages of the present invention will be readily appreciated as the same becomes better understood after reading the subsequent description taken in conjunction with the accompanying drawings.

BRIEF DESCRIPTION OF THE ACCOMPANYING DRAWINGS

[00027] The accompanying drawings constitute a part of the description and are used to provide a further understanding of the present invention. Such accompanying drawings illustrate the embodiments of the present invention used to describe the principles of the present invention. The embodiments are illustrated by way of example and not by way of limitation in the figures of the accompanying drawings in which references indicate similar elements. It should be noted that references to "an" or "one" embodiment in this invention are not necessarily to the same embodiment, and they mean at least one. In the drawings:

[00028] **Fig. 1** illustrates a Bathtub Reliability Curve for a Battery Management System (BMS) Printed Circuit Board Assembly (PCBA), as per the Military Hand Book Standard, in accordance with prior art;

[00029] **Fig. 2** illustrates a practical reliability curve for a BMS PCBA, in accordance with an embodiment of the present invention;

[00030] **Fig. 3** illustrates a step-up Highly Accelerated Life Testing (HALT) implementation for predicting failure and reliability, in accordance with an experimental data of the present invention;

[00031] **Fig. 4** illustrates a workflow block diagram for predicting failure and reliability of a BMS PCBA, in accordance with the present invention;

[00032] **Fig. 5** illustrates a block diagram for analyzing and predicting life of a BMS PCBA based on various test conditions, in accordance with an embodiment of the present invention;

[00033] **Fig. 6** illustrates a block diagram for life curve prediction of components of a BMS PCBA, in accordance with an embodiment of the present invention;

[00034] **Fig. 7 A** illustrates stress and strain effect on a BMS PCBA due to vibrations, in accordance with an embodiment of the present invention;

[00035] **Fig. 7B** illustrates components a BMS PCBA experiencing the thermal derating, in accordance with an embodiment of the present invention;

[00036] **Fig. 7C** illustrates the accelerometer response at various location on BMS PCBA, in accordance with an embodiment of the present invention; and

[00037] **Fig. 8** illustrates a block diagram for hardware design process for a PCBA, in accordance with an embodiment of the present invention;

[00038] **Fig. 9** illustrates general architecture of the system for implementation, in accordance with an embodiment of the present invention.

DETAILED DESCRIPTION OF THE INVENTION

[00039] The detailed description set forth below is intended as a description of various embodiments of the present invention. It is not intended to represent the only embodiments in which the present invention may be practised. Each embodiment described in this disclosure is provided merely as an example or illustration of the present invention and should not necessarily be construed as preferred or advantageous over other embodiments. The detailed description includes specific details to provide a thorough understanding of the present invention. However, it will be apparent to those skilled in the art that the present invention may be practised without these specific details.

[00040] As used in the description herein and throughout the claims that follow, the meaning of "a," "an," and "the" includes plural reference unless the context clearly dictates otherwise. Also, as used in the description herein, the meaning of "in" includes "in" and "on" unless the context clearly dictates otherwise.

[00041] If the specification states a component or feature "may", "can", "could", or "might" be included or have a characteristic, that particular component or feature is not required to be included or have the characteristic.

[00042] With increasing use of electric vehicles, the optimization of battery performance has become an important field of research and development. Battery Management system (BMS) is one of the core subsystems of the battery energy storage system. As an important link connecting onboard batteries and control units, BMS can optimize the battery performance by estimating the state of charge of the battery in real-time, preventing over-charging and over-discharging of the batteries, detecting state of battery health, and directly controlling functioning of batteries.

[00043] Generally, BMS is represented as a Printed Circuit Board Assembly (PCBA) or a hardware box. A Printed Circuit Board (PCB) for a Battery Management System (BMS) is a key hardware component that connects and supports various electronic components required for monitoring, protecting, and managing battery packs. The BMS PCBA mainly comprises of battery management controller, voltage and current sensors, temperature sensors, cell balancing circuit, communication interface and power management circuit. The PCB serves as the backbone of the BMS, enabling communication between sensors, controllers, and other peripherals. To ensure robustness, integrity and optimum working of the BMS for a longer time accurate reliability and failure calculation of the PCBA is very important.

[00044] In order to analyse possible malfunctioning or failure of electronic equipment in shorter duration before starting bulk production, Accelerated Life Testing (ALT) of the electronic equipment has been introduced. A highly accelerated life test (HALT) is a type of qualitative accelerated testing wherein the electronic equipment is subjected to extreme environmental and operational stress conditions, beyond its specified operating limits, to force early failures. This process enables design engineers to address potential weaknesses and improve product robustness before mass production. The HALT analysis of BMS PCBA still involves substantial time and cost. Therefore, to make the process of reliability analysis more robust and cost effective the HALT analysis can be performed in a simulating environment using an algorithm.

[00045] Ansys Sherlock software is one of the algorithms, which helps in life prediction of the PCBAs based on the different environments, which a system undergoes during its lifetime. SAE J3168 has a core document which includes conducting Reliability Physics Analysis (RPA) on the electronic and electrical components as the baseline process which includes to analyse the thermal cycling fatigues, vibration failures, Component shock and microcircuit failures due to wear-out.

[00046] **Fig. 2** illustrates a practical reliability curve **200** for a BMS PCBA, in accordance with an embodiment of the present invention. As illustrated, Fig. 2 captures the malfunctions arising due to premature failures, latent failures and random failures of components of a PCBA. These are the situations where Computer Aided Engineering (CAE) helps for simulating the worst-case scenario and how the system reacts to such a scenario.

[00047] As illustrated, the PCBA is prone to latent failures that may manifest over time due to minor manufacturing variations or process errors. These failures often remain

undetected during initial quality control and only become apparent after prolonged use, leading to performance degradation, intermittent faults, or complete system failure. Understanding the root causes of these latent failures is essential for improving PCB reliability and reducing warranty costs. The latent failure of PCBA can arise due to Soldering Defects, PCB Layer Misregistration, Plating and Via Defects, Component Misplacement and Orientation Errors, Delamination and Insufficient Lamination Adhesion, Micro-Cracks and PCB Flexure. Further, weak design of the PCBA may lead to a premature wear-out of the system. True Random Failures in a PCB assembly is rare and occur without any identifiable pattern, root cause, or predictable timeline. Unlike systematic failures caused by design flaws or manufacturing defects, true random failures result from inherent variability in materials, processes, and operational environments. These failures are independent of product age or operational history and typically occur during the useful life period of the product, where the failure rate is relatively constant.

[00048] **Fig. 3** illustrates a step-up Highly Accelerated Life Testing (HALT) implementation for predicting failure and reliability **300**, in accordance with an embodiment of the present invention. As illustrated in Fig. 3 step-up HALT is a structured and systematic stress-testing approach where environmental and operational stress levels are incrementally increased over the PCBA in predefined steps until operational and destruct limits of the product are identified. Each stress level is maintained long enough to detect failure mechanisms, with the goal of identifying weak links in the design and enhancing product robustness.

[00049] As illustrated in **Fig. 3,** a typical HALT profile involves applying multiple types of stress incrementally in different domains, such as thermal analysis where temperature cycling is performed and vibrational analysis where vibration stress is provided. In thermal analysis, the process starts with ambient temperature and increases in steps. The temperature dwells at each temperature level to allow thermal stresses to accumulate. The temperature continues to increase until operational and destruct limits are identified. At the threshold level the temperature is abruptly decreased followed by step-down decrease to a threshold level. This is followed by rapid thermal cycle test where temperature is decreased and increased to a threshold temperature. At each step, a particular temperature is allowed to dwell for a given duration so as to allow accumulation of stress in the PCBA. In order to detect vibration-induced mechanical and electrical failure, the PCBA is exposed to a baseline vibration level. The vibration level is incrementally increased to a threshold level and at each step the

vibration level dwells for given time period so as to allow accumulation of the vibrational stress. This is followed by combined vibrational and thermal stress to identify synergistic failure modes caused by combined thermal and vibration stress.

[00050] **Fig. 4** illustrates a workflow block diagram **400** for predicting failure and reliability, of a BMS PCBA, in accordance with the present invention. As illustrated, the first step **402** involves providing input in the form of Gerber Files. The Gerber files are a type of file format used to describe PCBA designs, containing the necessary data for a PCBA manufacturing specifying the layout of each layer, including copper traces, solder mask, component placement, and silkscreen. Second step **404** involves defining components package types, lead geometry, lead dimensions, and rated minimum and maximum temperatures. This is followed by third step **406** which involves defining thermal and vibrational stress events. This helps to define stress parameters and boundary conditions for subsequent reliability modelling of the PCBA. In step four **408**, different HALT analysis is performed which involves: Solder Fatigue Analysis, Thermal Derating Analysis, Thermal Mechanical Analysis and Vibrational Analysis. These steps have been further explained, in detail with reference to **Fig. 5**. In step 5 **410**, the analysis of results helps to identify failure mechanisms before deployment. A detailed analysis of the results can help to extended lifespan of the BMS PCBA by enhancing design through corrective actions.

[00051] In an embodiment, the HALT analysis of the components of the BMS PCBA is simulated using an algorithm. An Ansys Sherlock software is one of the algorithms which helps for life prediction of PCBAs based on the different thermal and vibrational stress environments a system undergoes during its lifetime. After HALT analysis of the PCBA, the data is provided to the Ansys Sherlock software. The software helps to analyse and subsequently identify failure points and failure modes for each of the component of the PCBA. After identification, subsequent corrective measures are taken by an operator by selecting new combination of materials, changing location. The HALT analysis is once again simulated by the software to provide predictive failure calculation for the modified configuration of the PCBA. The algorithm provides a reliability score for each of the plurality of components located on the PCBA. A higher score indicates that the component has better reliability under extreme conditions. The algorithm also provides a board-level PCBA design with high reliability score. This provides an overall design evaluation of the PCB to assess its reliability and overall lifecycle. The algorithm also provides a physical map identifying weak reliability points on the PCBA. Based upon points identified, an operator can take remedial

steps or select new selection of material to enhance reliability score of the PCBA. This algorithm for virtual HALT analysis in a simulating environment also allows saving of time and cost by avoiding re-running the thermal and vibrational analysis of the PCBA.

[00052] **Fig. 5** illustrates a block diagram for analyzing and predicting life of a BMS PCBA **500** based on various test conditions, in accordance with an embodiment of the present invention. As illustrated, the test conditions involve thermal analysis and vibrational analysis. The thermal analysis involves Solder Fatigue Analysis, Thermal Derating Analysis, Thermal Mechanical Analysis.

[00053] **Solder Fatigue Analysis 502**: Solder is used to join the components to the Printed Circuit Board (PCB) and is made up of metallic alloys which are made of different metal compositions. Most common alloy combination is Tin or lead metal combined with Silver or Brass. Fatigue failure of these joints are more likely to happen due to thermal cycling and one of the major causes for failure of electronic components. Fatigue properties are greatly influenced by the PCB properties, stresses and component's geometry. During the thermal cycling, the component and PCB may expand or contract due to differences in their Coefficient of Thermal Expansion (CTE). This causes a stress in the joints and the repeated thermal cycling may lead to high strains and can damage the solder. And if the temperature increases higher then it may lead to failure of the joint. These failures occur due to improper selection of the solder material during the design.

[00054] HALT tool calculates the cycle to failure using the strain energy density ((ΔW))

$$\Delta W = \frac{\sigma solder * \varepsilon solder}{2}$$

where σ → Solder Stress

Ɛ → Solder Strain

$$Nf = (Strain\ energy\ coefficient * \Delta W)^{-1}$$

where N_f → Number of cycles to failure

Strain energy coefficient depends on the solder material being selected and is based on the temperature profile (thermal event) the cycle to failure is adjusted depending on it. The calculation is a s follows -

$$Ramp\ rate = \frac{\Delta T}{Ramp\ Time}$$

$$\Delta T = (Maximum\ Temperature) - (Minimum\ Temperature)$$

$$Adjusted\ Cycle\ to\ failure = \frac{Original\ Cycles\ to\ Failure}{Thermal\ Shock\ Factor}$$

where Ramp time is the dwell time in the thermal event

Thermal Shock Factor (TSF) is the correction factor added based on the ramp rate. When ramp rate below 15°C/ minute then TSF = 1, between 15°C/ minute and 30°C/ minute, then TSF is interpolated between 1 and 1.25,

between 30°C/ minute and 60°C/ minute, then TSF is interpolated between 1.25 and 1.5 and when it is above 60°C/ minute then the TSF is 1.5

[00055] The most common solder materials which are being used are lead free and Tin lead. Tin Lead is mostly used where the fast flow of current is required. Lead free solders have a high melting point and create hard joints when soldering compared to lead soldering methodology. Few commonly used solder materials in industry are-

- SAC 305 → It is a lead free alloy which is made up composition of 96.5% Tin (Sn), 3% Silver (Ag) and 0.5% Copper (Cu)
- SENJU M794 → A lead free alloy with a combination of Tin (Sn), Silver (Ag), Copper (Cu), Bismuth (Bi) and Nickel (Ni)
- SN100C → It is a high purity, silver-free alloy containing Tin, Copper, Nickel, Germanium
- 63SN37PB → It is Tin lead solder material which consists of 63% Tin and 37% Lead
- PB90SN10 → It is Tin lead solder material with 90% Lead and 10% Tin

The leaded solder materials are mostly used in high temperature applications and places where high stability and reliability should be needed like aerospace and military. The lead-free materials offer good mechanical strength and resistance to thermal fatigue and are reliable. Mostly in the present application lead free materials are used.

[00056] **Thermal Derating Analysis 504**: In this analysis the rated minimum and maximum temperatures of the components is being compared to the thermal events minimum and maximum temperatures. If the PCBA component's rated temperatures could not

withstand the thermal event then there is a chance that the component starts derating if the same temperature cycle is being applied for prolonged periods. This analysis gives insights on the components that need to be taken care of in cases of operating at temperatures beyond the expected.

[00057] Thermal Mechanical Analysis 506: In a PCB, the flow of high current can cause the warpage of PCB due to high heat density and leads to failure in critical cases. These failures are mostly due to the difference in coefficient of thermal expansion. Different expansion rates can deform the component and account for the stress in those places. The HALT tool creates a Finite element model for the analysis and performs a static linear structural analysis with uniform temperature as per the event and these temperatures are applied through the mount points. Structural analysis is performed in two steps - the tool performs analysis for minimum and maximum temperatures separately and the equivalent strain is considered. Hydrostatic stress (HS) is used to say whether the element is in tension or compression. Element is in tension if HS is positive and in compression when HS is in negative.

$$\sigma_{hyd} = \frac{(SX + SY + SZ)}{3}$$

where σhyd → Hydrostatic Stress

SX,SY, and SZ are stress components in each direction.

[00058] Plated-through-hole (PTH) Fatigue 508: PTHs are conductive holes that connect different layers of a PCB, allowing for electrical connections between components on different sides of the board. The copper plating in PTHs has a different coefficient of thermal expansion (CTE) compared to the PCB's base material. When the PCB experiences temperature changes, the copper and the surrounding material expand or contract at different rates, creating stress on the PTH barrel (the copper plating). Repeated thermal cycling can cause these stresses to build up, leading to fatigue and cracking of the PTH barrel, ultimately resulting in open circuits or intermittent connections.

[00059] Vibrational Analysis 514: Throughout the life cycle, an electric vehicle (EV) experiences various vibrational loads. To understand the board dynamics; vibrational analysis is carried out. Since, the electronic components are soldered to the PCB board, during

vibrations, a dis-connectivity may occur. Further, it may result in a component failure due to fatigue. Excessive deformations and acceleration results in the damage of mounted components and solder joints and electrical interfaces on the PCB. The vibrational analysis is performed for vibrational step stress and combined thermal and vibrational step stress. After the application of this pulse, the PCB vibrates at its natural frequency and a maximum strain and stress occurs during a high G load application period. During application of load a high cycle fatigue, a low cycle fatigue and an overstress mechanism occur in the components of the PCB. The cycle to failure is calculated by the Coffin-Manson Basquin equation which relates to stress and strain. And with these equations the number of high cycle (N_f- high cycle) and low cycle fatigue (N_f- low cycle) cycles can be calculated

$$N_{f-highcycle} = 10e^6 * \left(\frac{\varepsilon_c}{2 * \varepsilon_{FEA}}\right)^{FEA\ power}$$

$$N_{f-lowcycle} = 1000 * \left(\frac{\varepsilon_c}{\varepsilon_{FEA}}\right)^2$$

where Ɛc → Component Critical Strain

ƐFEA → FEA footprint strain of the given component

FEA power → Fatigue exponent for the solder material being used.

[00060] The repeated thermal and vibrational cycles result in semiconductor wear out. The results of thermal and vibrational analysis if further provided for Design Failure Mode and Effects Analysis (DFMEA) **516**. The DFMEA **516** is a systematic process used in product design to identify potential failure modes, analyse their effects, and implement preventative measures to enhance product safety and quality. Based upon data collected, a combined plot is prepared for life curve prediction of components of the PCBA for the battery management system as illustrated in Fig. 6.

[00061] **Fig. 6** illustrates a block diagram for life curve prediction **600** of components of a BMS PCBA, in accordance with an embodiment of the present invention. As illustrated in order to graphically represent life cycle of components of the PCBA, different phases and events are defined which accounts the usage or scenarios used throughout service life of the PCBA. Each event defined has a duration and how often the event occurs (frequency) and that accounts for the contribution to the main life phase of the PCBA. The exposure time

(duration) of the event represents part of the total service life when the event is actually applied. Based on this total number of cycles to fail and total damage is being computed and a curve is plotted to define probability of failure.

[00062] **Fig. 7 A** illustrates stress and strain effect due to vibrations; **Fig. 7B** illustrates components a BMS PCBA experiencing the thermal derating; **Fig. 7C** illustrates the accelerometer response at various location on BMS PCBA, in accordance with an embodiment of the present invention. As illustrated in Fig. 7A, vibration-induced stress and strain are among the most critical factors affecting the reliability of a Printed Circuit Board Assembly (PCBA), particularly in applications such as automotive, aerospace, and industrial electronics. Prolonged exposure to mechanical vibrations can induce fatigue, cracks, and component dislodgement, leading to operational failure. As illustrated in Fig. 7B, components on a BMS PCBA are subject to thermal derating, where their performance and reliability degrade when operating at elevated temperatures. Understanding thermal derating and its impact on various BMS components is essential to enhance system reliability and extend lifespan. Components in a BMS PCBA are typically rated for optimal performance within a defined temperature range. Exceeding this range results in Reduced current-carrying capacity, increased failure rates, and accelerated aging and degradation. As illustrated in Fig. 7C, accelerometer measurements are essential in ensuring the mechanical integrity and reliability of the BMS, especially in automotive, aerospace, and industrial applications where harsh operating environments can introduce mechanical stress and potential failure. It helps to understand how mechanical vibrations and shock impact different locations of the PCB. Based upon readings of an accelerometer critical locations for vibration measurement on a PCBA can be identified.

[00063] **Fig. 8** illustrates a block diagram for hardware design process for a PCBA **800**, in accordance with an embodiment of the present invention. As illustrated, Fig. 8 provided the hardware design process. The hardware design process for the PCBA involves a series of well-defined steps that ensure the creation of a reliable, functional, and manufacturable electronic system. This process includes system-level design, component selection, schematic capture, PCB layout, prototyping, and testing (not illustrated in drawing). Hardware specifications are provided for fabrication of PCB functional block, housing, connectors and a schematic drawing is prepared. At these stages of providing hardware specifications virtual tools can help an operator to take the decisions. The virtual tool can help in the part selection

process and solder selection process through thermal derating and solder fatigue analysis and understanding the position of mount points virtually.

[00064] **Fig. 9** illustrates general architecture of the system **900** for implementation, in accordance with an embodiment of the present invention. As illustrated, a Battery Management System (BMS) **902** comprising of a Printed Circuited Board Assembly (PCBA) **904** is in communication with a system **906** for virtual Highly Accelerated Life Testing (HALT) analysis. The system **906** performs the HALT analysis of a plurality of components located on the PCBA **904** of the BMS **902** in a simulating environment. The system **906** comprises of a processor **908**, a memory **918** and a display unit **920**. The data from the PCBA **904** is provided to the system **906** on real time basis. The processor **908** performs a reliability calculation of the PCBA **904**. In order to provide a reliability score to the plurality of components of the PCBA **904**, the processor **908** implements a plurality of modules which includes Solder Fatigue Analysis Module **910**; Thermal Derating Analysis Module **912**; Thermal Mechanical Analysis Module **914**; Vibrational Analysis Module **916**.

[00065] The Solder Fatigue Analysis Module **910** analyses data of the solder joints of the plurality of components in real time. Solder fatigue occurs due to the gradual degradation of solder joints under repeated thermal and mechanical stress. The failure is primarily due to Creep, Plasticity, and Crack Propagation caused by thermal cycling, aging, vibration and mechanical shocks. The HALT analysis using an algorithm and/or computer program such as Ansys Sherlock software provides real time operating behavior of the solder joints of semiconductor located on the PCBA **904**. Based upon prediction and failure data obtained from the solder fatigue analysis module **910**, an operator can undertake essential design changes of the PCBA **904** for ensuring long-term product reliability.

[00066] The Thermal Derating Analysis Module **912** analyses data of junction temperature of the semiconductors present in the PCBA **904** in real time. A higher junction temperature accelerates aging of the components resulting in time-dependent dielectric breakdown and electromigration. Applying step-up increasing HALT stress provides data regarding temperature variation at various junctions of the semiconductor. The HALT analysis using an algorithm and/or computer program such as Ansys Sherlock software provides real time operating behavior of the junctions of semiconductor located on the PCBA **904**. Based upon prediction and failure data obtained from the thermal derating analysis module **912**, the operator can undertake essential design changes of the PCBA **904** for ensuring long-term product reliability.

[00067] The Thermal Mechanical Analysis Module **914** analyses data of combined effects of thermal and mechanical stresses on the PCBA **904** in real time. It provides data predicting deformation, fatigue, and failure mechanisms caused by thermal cycling, vibration, and mechanical loads, ensuring long-term reliability and performance of electronic systems. The HALT analysis using an algorithm and/or computer program such as Ansys Sherlock software provides real time operating behavior of the components under thermal and mechanical stress located on the PCBA **904**. Based upon prediction and failure data obtained from the thermal mechanical analysis module **914**, the operator can undertake essential design changes of the PCBA **904** for ensuring long-term product reliability.

[00068] The Vibrational Analysis Module **916** analyses data of the impact of mechanical vibrations on PCBA **904** in real time. This allows to predict fatigue, deformation, and failure mechanisms of the components located on the PCBA **904**. The vibrations encountered during operation of an electric vehicle on the roads can cause fatigue, micro-cracks, and interconnect failures on the PCBA **904**. The HALT analysis using an algorithm and/or computer program such as Ansys Sherlock software provides real time operating behavior of the components under vibrational stress located on the PCBA **904**. Based upon data prediction and failure data obtained from the vibrational analysis, the operator can take essential design changes of the PCBA **904** for ensuring long-term product reliability. Based upon prediction and failure data obtained from the vibration stress analysis module **916**, the operator can undertake essential design changes of the PCBA **904** for ensuring long-term product reliability.

[00069] In an example, the processor(s) may be a single processing unit or a number of units, all of which could include multiple computing units. The processor(s) may be implemented as one or more microprocessors, microcomputers, microcontrollers, digital signal processors, central processing units, logical processors, virtual processors, state machines, logic circuitries, and/or any devices that manipulate signals based on operational instructions. Among other capabilities, the processor(s) is configured to fetch and execute computer-readable instructions and data stored in a memory.

[00070] The memory may include any non-transitory computer-readable medium known in the art including, for example, volatile memory, such as static random-access memory (SRAM) and dynamic random-access memory (DRAM), and/or non-volatile memory, such as read-only memory (ROM), erasable programmable ROM, flash memories, hard disks, optical disks, and magnetic tapes.

[00071] In an example, the module(s), engine(s), and/or unit(s) may include a program, a subroutine, a portion of a program, a software component or a hardware component capable of performing a stated task or function. As used herein, the module(s), engine(s), and/or unit(s) may be implemented on a hardware component such as a server independently of other modules, or a module can exist with other modules on the same server, or within the same program. The module (s), engine(s), and/or unit(s) may be implemented on a hardware component such as processor one or more microprocessors, microcomputers, microcontrollers, digital signal processors, central processing units, state machines, logic circuitries, and/or any devices that manipulate signals based on operational instructions. The module (s), engine(s), and/or unit(s) when executed by the processor(s) may be configured to perform any of the described functionalities. In an alternate embodiment, the functions of the aforesaid modules may be performed by the processor(s).

[00072] In an example, one or more display unit may include a computer monitor, a touch screen, an output device capable of displaying the graphics, and the like. The display unit is configured to display visual output in desktops, laptops and workstations. The display unit **1004** may come in different sizes, resolutions, and types (such as LCD, LED, or OLED).

[00073] It is to be understood that the disclosure is not to be limited to the specific embodiments disclosed, and that modifications and other embodiments are intended to be included within the scope of the appended claims. Although specific terms are employed herein, they are used in a generic and descriptive sense only and not for purposes of limitation, unless described otherwise.

[00074] Any combination of the above features and functionalities may be used in accordance with one or more embodiments. In the foregoing specification, embodiments have been described with reference to numerous specific details that may vary from implementation to implementation. The specification and drawings are, accordingly, to be regarded in an illustrative rather than a restrictive sense. The sole and exclusive indicator of the scope of the invention, and what is intended by the applicants to be the scope of the invention, is the literal and equivalent scope of the set as claimed in claims that issue from this application, in the specific form in which such claims issue, including any subsequent correction.

We claim:

1. A method for reliability calculation of a Printed Circuit Board Assembly (PCBA) (904), the method comprises:

performing High Accelerating Life Testing (HALT) analysis of a plurality of components located on the PCBA in a simulating environment, the HALT analysis includes:

providing PCBA (904) layout information so as to draw virtual pattern of the plurality of components;

determining sequence of a plurality of testing parameters;

setting a targeted failure rate;

monitoring performance and obtaining data for each of the plurality of testing parameters; and

analyzing data so as to predict failure rate of the PCBA (904), accurately.

2. The method for reliability calculation of the PCBA (904) as claimed in claim 1, wherein the plurality of testing parameters comprises:

Solder Fatigue Analysis (502);

Thermal Derating Analysis (504);

Thermal Mechanical Analysis (506); and

Vibrational Analysis (514).

3. The method for reliability calculation of the PCBA (904) as claimed in claim 1, further comprising providing a reliability score for each of the plurality of components located on the PCBA (904).

4. The method for reliability calculation of the PCBA (904) as claimed in claim 1, further comprising providing a board-level PCBA (904) design with high reliability score.

5. The method for reliability calculation of the PCBA (904) as claimed in claim 1, further comprising providing a physical map for weak reliability points on the PCBA (904).

6. The method for reliability calculation of the PCBA (904) as claimed in claim 1, further comprising detecting deviation of performance of the plurality of components located on the PCBA (904) from standard data.

7. The method for reliability calculation of the PCBA (904) as claimed in claim 1, further comprising providing design recommendation to an operator for increasing reliability of the PCBA.

8. The method for reliability calculation of the PCBA as claimed in claim 1, wherein the PCBA (904) is for a Battery Management System (BMS) (902) of an electric vehicle.

9. A system (906) for reliability calculation of the PCBA (904) comprising:

a processor (908);

a memory (918); and

a display unit (920), wherein the processor is configured to perform the HALT analysis of the plurality of components located on the PCBA (904) of the BMS (902) in a simulating environment.

10. The system for reliability calculation of the PCBA (902) as claimed in claim 9, wherein the processor (908) implements a plurality of modules for the HALT analysis, the module comprises:

Solder Fatigue Analysis Module (910);

Thermal Derating Analysis Module (912);

Thermal Mechanical Analysis Module (914); and

Vibrational Analysis Module (916).