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RELIABILITY OF BATTERY MANAGEMENT SYSTEM MODULE UNDER SIMULTANEOUS EXPOSURE TO HIGH TEMPERATURE AND RANDOM VIBRATIONS

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Abstract: *In this paper, the impact of mechanical vibrations on the components of an electric vehicle is studied. Even if electric motors generate smaller vibrations than internal combustion engines, vibrations due to the external environment appear on the vehicle, which have a major impact on the reliability of the components. Any type of vibration that over time affects the operation of the components in a vehicle has a direct impact on the comfort and ergonomics of the driver and passengers in the vehicle. The purpose of the paper is to subject a PCB board to a vibration test to show what the permissible limit of vibrations up to which the structure of the board is not affected and implicitly its functionality.*
Key words: *Printed circuit board (PCB), vibration, ergonomics, reliability, electric.*

1. INTRODUCTION

The global automotive market has seen a significant increase in electric vehicles over the past few years, thanks to their ecological and economic advantages. However, the command modules of electric vehicles contain delicate printed circuit boards (PCBs), which can be affected by vibrations and mechanical shocks. Like in the case of internal combustion engine vehicles, the components of an electric vehicle are subject to vibration solicitations. These vibrations and shocks can lead to component failures, short circuits, and mechanical damage to the printed circuit boards, which can impact the functionality and reliability of electric vehicles. Vibrations transmitted to the vehicle's cabin can negatively affect the comfort and ergonomics of the driver and passengers. High levels of vibration can cause discomfort, fatigue, and stress, thus diminishing the user experience.

To ensure a high level of ergonomics and reliability, the evaluation and reduction of vibration impact are crucial in the design and operation of vehicles. This involves:

- Accurate measurement and detailed analysis of vibrations;
- Implementation of vibration isolation and damping solutions;
- Ergonomic design of components and the entire vehicle.

Although the level of vibrations under the hood of an electric car is lower than that of an internal combustion engine car, they are still present here. External environmental vibrations and mechanical shocks are felt similarly, and reducing these levels affects the quality and type of suspension systems, but this varies from one manufacturer to another. Automotive electronics, located in the engine compartment, can be exposed to combined mechanical vibrations and high-temperature operations. Studies have shown that the maximum operating temperature of an electronic component in a vehicle can reach 200°C, in the presence of a vibration level of up to 10g simultaneously [1].

Previous works have shown that electronic components subjected to simultaneous vibration and temperature stresses will degrade faster compared to electronic components subjected to a single type of stress [2],[3].

Vibrations, one of the loading conditions to which electronic assemblies are subjected, have become a crucial factor in evaluating the

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reliability of modern electronic systems. The main challenge lies in rapidly and accurately analyzing the fatigue caused by vibrations.

Various types of failures have been observed, including the fatigue of solder joints and the cracking of copper or lead residues caused by intense vibration cycles [4]. Despite this, only a few researchers have explored the reliability of solder joints under high temperature and vibration conditions simultaneously [5]. In addition, finite element models have been developed to estimate the lifespan under fatigue conditions, in association with degradation relationships for electronic components under the impact of a single load, mechanical vibrations. During the manufacturing process and throughout their operational lifetime, printed circuit boards (PCBs) are subjected to various thermal and mechanical loading conditions, such as thermal cycles, cyclic bending, drops, and vibrations.

Vibration loading, as one of the critical factors for electronic assemblies, has become essential in evaluating the reliability of modern electronic systems. The main challenge lies in achieving rapid and precise analysis of the lifespan under vibration stress.

Regarding the lifespan under fatigue conditions caused by vibrations, Pitarresi and colleagues [6-8] have explored methods for modeling printed circuit boards subjected to vibration loads. They analyzed the response of the boards and the solder joints mounted on the surface and predicted the lifespan in the context of random excitations. The material properties of the printed circuit board change during the transition through the glass transition region, with variations in operating temperature. These changes are quite significant and can influence the natural frequencies of the printed circuit assembly under vibration [9], [10].

2. TEST BOARD

In this research, the reliability of the BMS (Battery Management System) 6S, Li-Ion, 15A, 25.2V module under temperature and vibration is tested. The design of the BMS testing vehicle is presented in Figure 1. This BMS module is used to manage and protect lithium-ion batteries connected in series. It is used in various applications that require a reliable and protected energy source, such as energy storage systems, electric vehicles, electric scooters, electric bicycles, portable electronic devices, and other equipment that use lithium-ion batteries. This module ensures correct charging of the batteries, protecting them against overcharging, excessive discharging, and short circuits, thereby prolonging the lifespan of the batteries and ensuring the safety of users and equipment in which they are integrated.

The module was subjected to high temperatures of 85 degrees Celsius and random vibrations within a frequency range of 5-2000 Hz. The test was conducted in accordance with international standards IEC 60068-2-14 and IEC 60068-2-64. IEC 60068 is a collection of methods for environmental testing of electronic equipment and products to assess their ability to perform under environmental conditions, including extreme cold and dry heat. IEC 60068 offers appropriate severities and prescribes various environmental conditions for measurements and tests [11].

IEC 60068-2-14 is part of IEC 60068 provides a test to determine the ability of components, equipment, or other articles to withstand rapid changes of ambient temperature. The exposure time adequate to accomplish this will depend upon the nature of the specimen [12]

IEC 60068-2-64 is part of IEC 60068 demonstrates the adequacy of specimens to resist dynamic loads without unacceptable degradation of its functional and/or structural integrity when subjected to the specified random vibration test requirements [13].

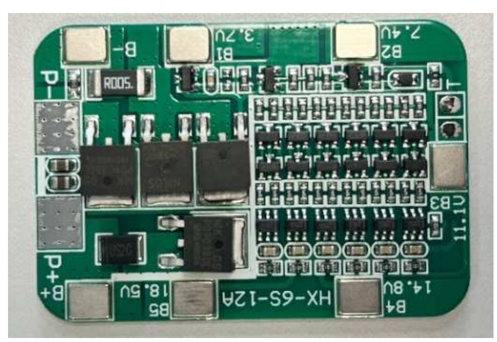

Fig. 1. BMS module used in this study.

Table 1

Test Board Characteristics

Dimension [mm]	53x35.5x1.2
Weight [g]	7.5

3. TEST EQUIPMENT AND SETUP

The test was performed using a climatic chamber and an electrodynamic shaker simultaneously. The equipment used for vibrations is a Shaker RMS model SW8500. With a power of up to 45 kN and water cooling, this shaker offers high performance and reliability in vibration tests (presented in Fig. 2).

The equipment used for the temperature test is a climatic chamber with a volume of 1200L. It is testing equipment specialized for controlled climatic conditions. The climatic chamber is specially designed to be attached to the shaker, making it possible for a product to be tested for vibrations and temperature simultaneously. This Equipment can maintain temperatures between -70°C and 180°C and humidity between 0% and 100%.

The climatic chamber is presented in Fig. 3. The test stand consists of a shaker, an amplifier, a controller, and a PC, which together enable the measurement and analysis of the vibrations produced by the shaker to determine its properties and behavior.

Accelerometers are used to measure the vibrations produced by the shaker and to determine its properties and behavior. The test stand is equipped with a vibration control and regulation system, which allows for adjusting the frequency and amplitude of the vibrations to obtain precise and repeatable results (Fig. 4).

The accelerometers are connected to the PC to collect and analyze vibration data and display the results. Although the vibration and temperature tests are performed simultaneously, they have separate data acquisition systems. The climatic chamber is controlled by a PC which, through software, simulates the climatic profile and collects the data at the end of the test (Fig. 5). In Fig. 6, the test stand for vibration and temperature testing is presented.

For this test, the shaker is oriented in a vertical position, and the module attachment to the fixture will be of the "sandwich" type. The "sandwich" attachment method is an efficient and safe way to attach a PCB to a shaker for vibration testing.

Fig. 2. Electrodynamic vibration test system [14].

Fig. 3. Climatic chamber [15].

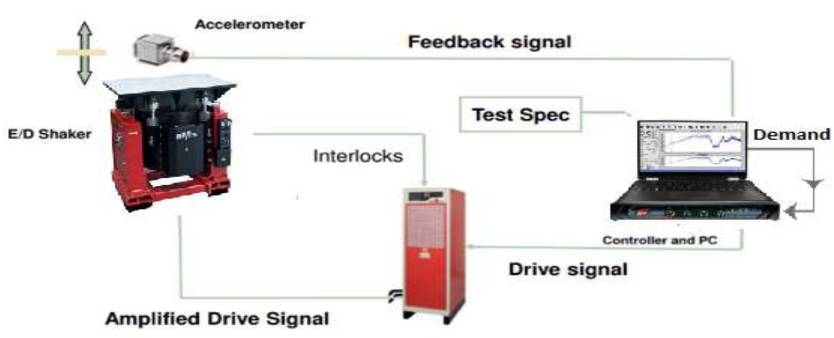

Fig. 4. Control loop for vibration test.

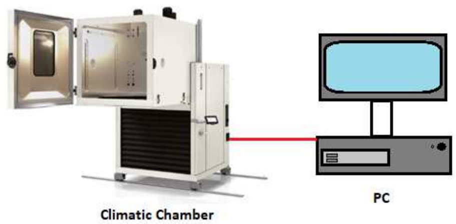

Fig. 5. Control loop for temperature test.

Fig. 6. Test equipment (Climatic chamber and Shaker).

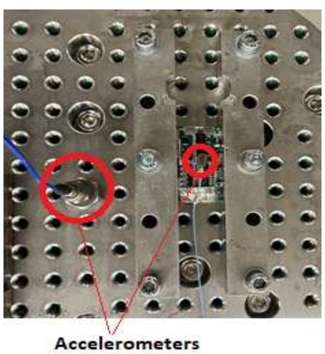

Fig. 7. Test setup with the control accelerometer mounted.

Fig. 8. Test setup, device under test

This method ensures a stable and secure attachment of the PCB, reducing the vibrations transmitted to the PCB and preventing component damage. In Fig. 7, the test setup is presented; as can be seen, a control accelerometer is mounted on the fixture, and another measurement accelerometer is mounted on the BMS module.

4. EXPERIMENTAL MODAL ANALYSIS

Before the start of the test, a sine-sweep profile will be used to determine the dynamic behavior of the product (Fig. 9). This test is performed before each random vibration test to find the natural frequency of the tested product, and after the test to see if the product has changed its mechanical properties.

For the sine-sweep test, a vibration profile with an amplitude of 2G and a range of 5-2000 Hz will be considered (Fig. 10). After completing the sine-sweep test, the resonance points were detected as presented in Table 2.

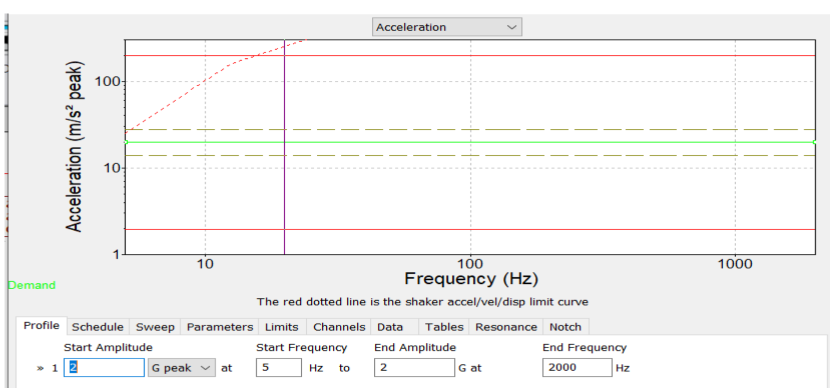

Fig. 9. Sine-sweep profile.

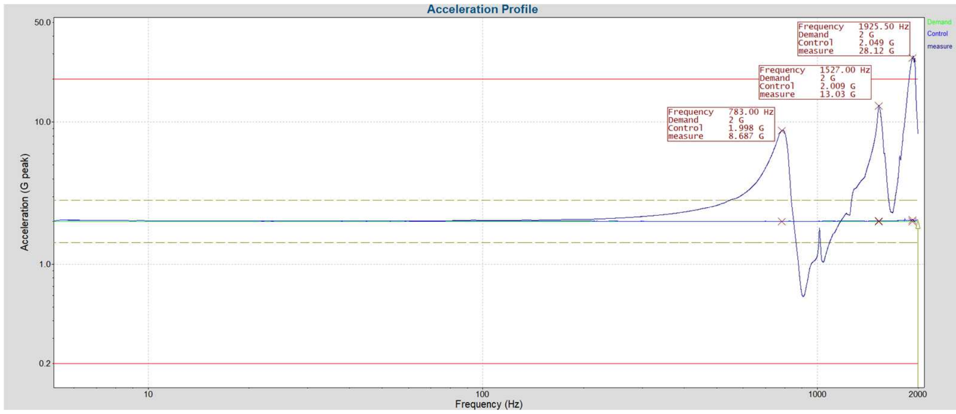

Fig. 10. Sine-sweep before random test results.

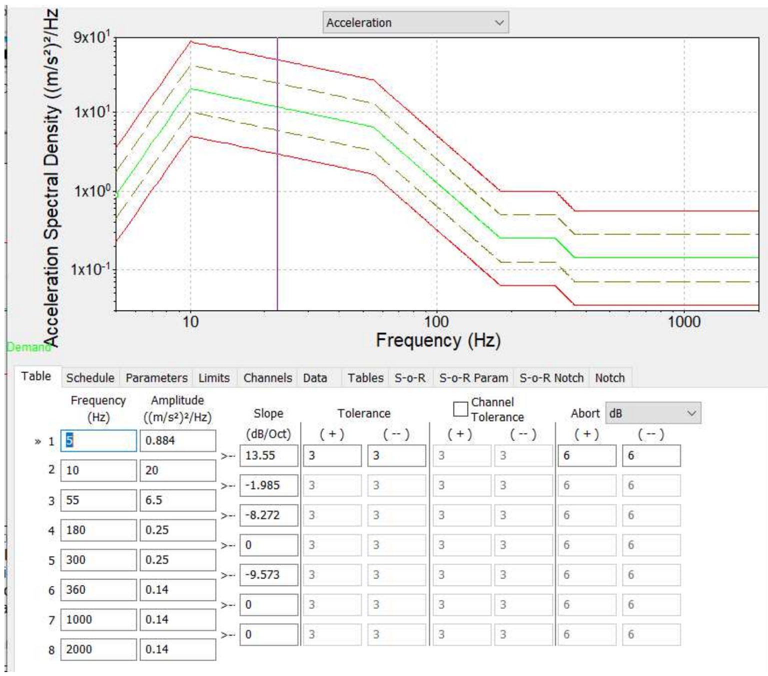

Fig. 11. Random profile.

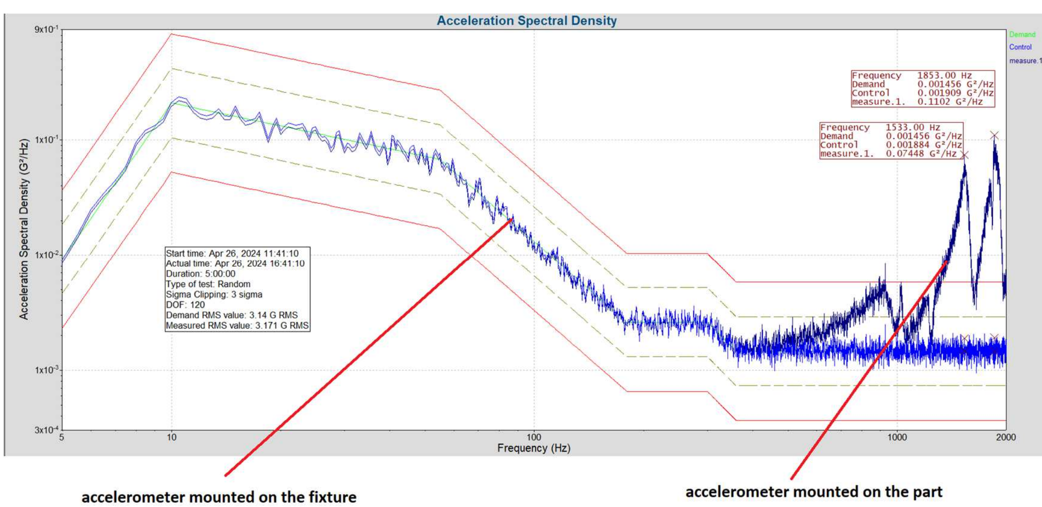

Fig. 12. Random test results.

Table 2

Resonance peaks before performing the vibration and temperature test.

Frequency (Hz)	Peak (G)
783	8.68
1527	13.03
1925	28.12

Table 3

Frequency.

Frequency (Hz)	PSD $(m/s^2)^2/H$
5	0.884
10	20
55	6.5
180	0.25
300	0.25
360	0.14
1000	0.14
2000	0.14
RMS acceleration	30.8 m/s^2

Table 4

Peaks measured random tests.

Frequency (Hz)	ASD (G^2/Hz)
1533	0.074
1853	0.11

Higher peaks indicate the frequency-location of the higher mode-shapes and natural frequencies (Fig. 10). After completing the sine-sweep test, the profiles for the random vibration and temperature tests were created.

For the random vibration and temperature tests, values found in testing electronic products from the automotive industry were used. These tests aim to accelerate the aging of products to determine their lifespan and identify any manufacturing defects before they enter the production process.

For the temperature test, a temperature profile was performed, starting from the ambient temperature of 25°C to 85°C, with a ramp of 1°C/min, the product being exposed to the maximum temperature for 4 hours, followed by a decrease in temperature to 25°C at a rate of 1°C/min, the total temperature test lasting 6 hours. The vibration test was extended to a duration of 5 hours, long enough to reveal any possible defects that could reduce the product's reliability.

For the vibration test, the following values were used, as described in Table 3, which are within the range of 5-2000 Hz. After introducing these values into the software of the shaker, the vibration profile (Fig. 11) will be generated. After the test, the equipment used generated the measurements based on the information provided by the measurement equipment. The graph is presented in Fig. 12.

After the test results are generated, it was found that the vibration values felt at the level of the tested piece are higher than those at the level of the fixture on which the piece is mounted (Table 4). The accelerometer mounted on the product measures higher vibrations than the accelerometer mounted on the fixture on which the product is attached due to the differences in how they are mounted and the resonance effects they produce in the testing system. These vibrations are influenced by the product's characteristics, such as mass, stiffness, and resonance frequencies, as well as its attachment method to the fixture. In Fig. 13, the result of the temperature test is presented, showing the temperature graph in which there were no undesirable deviations, and the test ran according to the requirements.

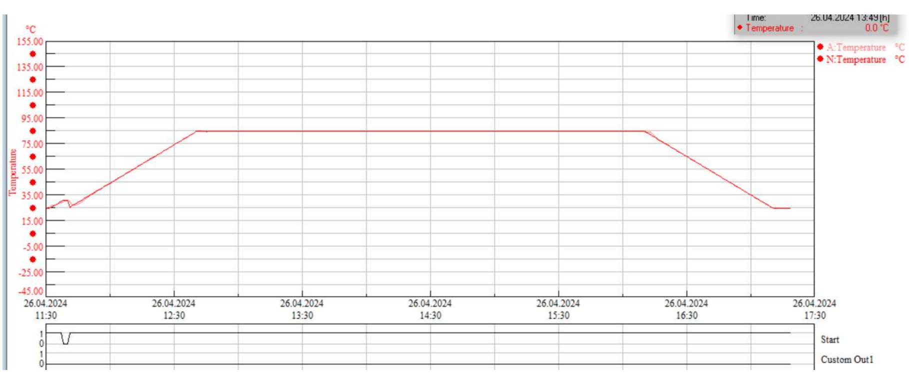

Fig. 13. Temperature test results.

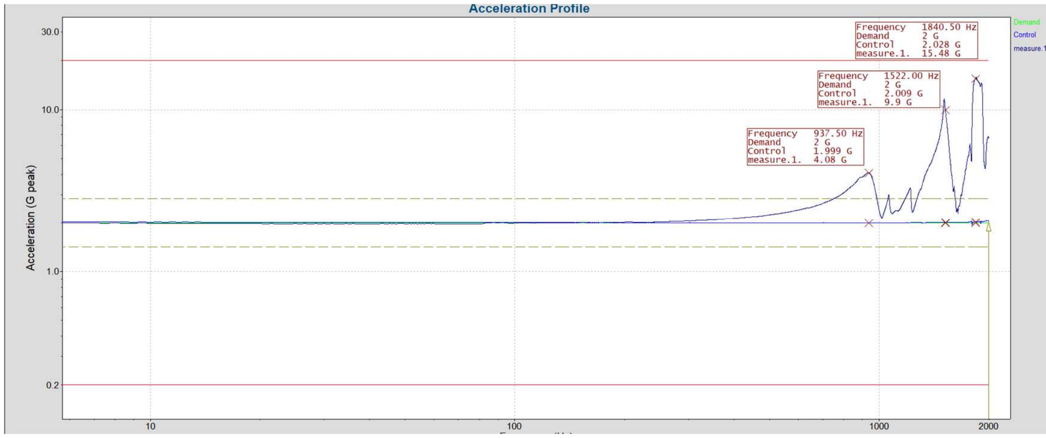

Fig. 14. Sine-sweep after random test results.

Table 5

Resonance peaks after performing the vibration and temperature test.

Frequency (Hz)	Peak (G)
937.5	4.08
1522	9.9
1840.5	15.48

After completing the random vibration and temperature tests, another sine sweep test will be performed to see if the behavior of the tested piece changes (Fig. 14). The profile and input parameters are the same as those at the beginning of the sine sweep test. After the test was completed, resonance points were detected as shown in Table 5.

5. CONCLUSIONS

The reliability of the 6S, Li-Ion, 15A, 25.2V BMS (Battery Management System) module was studied, with the product subjected to a combination of high temperature and random vibrations. Experimental modal analysis was performed to determine PCB characteristics such as natural frequencies and mode shapes.

The normal functioning of the battery management system (BMS) module is crucial for ensuring user safety and ergonomics, as any malfunction can precipitate failures, including short circuits, which may lead to a vehicle fire and thereby pose a significant risk to the lives of the driver and passengers.

After the test, the product does not show any mechanical defects. Although the tested part does not show visible defects, the resonance values measured at the end of the test are different from those measured before the test. In this case, the values differ due to changes in the product after the test, such as changes in stiffness or mass, which can influence the resonance frequency. Additionally, high temperatures can be a factor that influences the properties of the product, and consequently, the resonance frequency.

6. ACKNOWLEDGEMENTS

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Fiabilitatea sistemului de management al bateriei expus solicitărilor simultane la temperaturi ridicate și vibrații aleatorii

În cadrul aceastei lucrari se prezinti studiul impactului vibrațiilor mecanice asupra componentelor unui vehicul electric. Chiar dacă motoarele electrice generează vibrații mai mici decât motoarele cu ardere internă, în vehicul apar vibrații datorate mediului extern, care au un impact major asupra fiabilității componentelor. Orice tip de vibrație care în timp afectează funcționarea componentelor dintr-un vehicul are un impact direct asupra confortului și ergonomiei șoferului și pasagerilor din vehicul. Scopul lucrării este de a supune o placă PCB unui test de vibrații pentru a arăta care este limita admisă de vibrații până la care nu este afectată structura plăcii și implicit funcționalitatea acesteia.

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