

SAFETY TEST PROCEDURES, STANDARDS AND RESULTS FOR ELECTRIC BIKE BATTERY

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To My Family

ABSTRACT

Recently, battery project studies have been increasing worldwide. Companies carrying out these projects must have their products checked for design safety and must obtain test approval reports in order to release their products on the market. IEC 62133-2 test approvals are required for lithium-ion rechargeable batteries, and EN 50604 test approvals are necessary for rechargeable li-ion batteries used in Light EV (electric vehicles). In addition, UN38.3(IEC 62281) battery transport tests must be applied for the transport of these batteries. These tests should be performed in an accredited laboratory, the safety of the design should be verified in this way, and then an accredited report should be issued to the product. There was no accredited laboratory in Turkey that performed tests in accordance with these standards. For this reason, companies were receiving services from overseas laboratories for the cell and battery approvals that they designed. There could be time and financial problems in overseas laboratories approvals. Due to these problems, an accredited laboratory was established at Vestel Electronics in Turkey, where tests can be carried out in accordance with IEC 62133-2, EN50604, and UN38.3 (IEC 62281) standards. Since batteries contain BMS cards, their tests are also carried out in this laboratory. Within the scope of this accredited laboratory established in Turkey, it will be stated how the test setups that meet the test requirements are set up. Test results with these devices will be evaluated. The test results will belong to an E-bike battery project.

ÖZETÇE

Son zamanlarda tüm dünyada batarya proje çalışmaları artmaktadır. Bu projeleri yürüten firmalar, ürünlerinin tasarım güvenliğini kontrol ettirmeli ve ürünlerini piyasaya sürmek için test onay raporları alması gerekmektedir. Lityum iyon içeren şarj edilebilir bataryalar için IEC62133-2 test onayları ve Hafif EA' da (elektrikli araç) kullanılan şarj edilebilir lityum iyon piller için EN 50604 test onayları gerekmektedir. Ayrıca bu bataryaların taşınması içinde ekstra UN38.3 batarya taşıma test onayları uygulanmalıdır. Bu testler akredite bir laboratuvarda uygulanmalı, tasarımın güvenliği bu şekilde doğrulanmalı ve sonrasında ürüne akredite bir rapor düzenlenmelidir. Bu standartlara uygun test gerçekleştiren akredite bir laboratuvar Türkiye'de bulunmamaktaydı. Bu nedenle firmalar tasarladıkları cell ve batarya onayları için yurtdışı laboratuvarlarından hizmet almaktaydı. Yurtdışı onaylarında süre ve maddi anlamda sorunlar oluşabilmekteydi. Bu sorunlara karşı Türkiye Vestel Elektronik A.Ş'de IEC62133-2, EN50604 ve UN38.3(IEC62281) standartlarına uygun testlerin gerçekleştirilebildiği akredite bir laboratuvar kuruldu. Türkiye'ye kazandırılan bu akredite laboratuvar kapsamında test gerekliliklerini karşılayan setuplar'ın nasıl kurulduğu ve test sonuçları aktarılacaktır. Test sonuçları bir E-bike batarya projesine ait olacaktır.

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CHAPTER I

INTRODUCTION

Recently, studies have been carried out for many battery projects in Turkey. Factories are being established, and there are many battery investment studies. Turkish investors want to develop the battery technology used in many products with R&D studies[1]. In the future, the battery will be of great importance in the world. Companies in Turkey have started essential studies on this battery technology. There are many requirements, such as production facilities and test-approval laboratories, for these battery projects to be put on the field. New cell and battery factories have been established in Turkey. Investments in these processes are increasing. But there are no laboratories that validate E-bike li-ion batteries. The produced batteries or cells should obtain approval certificates before selling them. These approvals are essential requirements. Since no laboratories provide these approvals in Turkey, products are sent to foreign accredited laboratories for testing and approval. There are many disadvantages of carrying out these approval processes from a foreign market. For example, the cell or battery for which R&D work is carried out must be shipped abroad. Since these products are not approved and their transportation is risky, many complex transportation procedures occur. This long and challenging transportation process affects the project schedule. In the approval processes received from abroad, the R&D teams do not have a chance to intervene in the problem that occurs during any test immediately. In addition, access to the results obtained during the tests is restricted. If the project schedules of the laboratories where the products are sent for testing are busy, the approval processes may be longer. These situations affect the approval schedules of the projects planned to be developed in Turkey. It is not

possible to start the production of a product without validating the design and passing the approval tests successfully. In a critical situation, it is necessary to perform these tests in accredited laboratories with appropriate devices. These tests are most appropriately performed in accredited laboratories. Accredited laboratories are those whose suitability has been audited. If the result of the tests required to bring the product to the market is successful, documents and certificates are prepared. Some of the necessary procedures for sales are these approval certificates and documents. Certification Body (CB) reports are also required to launch products to the overseas market[2]. CB reports state that the products are tested and approved according to International Electrotechnical Commission (IEC) standards in an accredited laboratory. These CB reports can be obtained from Certification Body Testing Laboratory (CBTL) laboratories that perform tests in accordance with IEC standards. In order to issue a CB report to the market, it is necessary to be a CBTL lab or a Customer Testing Facilities (CTF) laboratory. CTF laboratories must sign agreements with CBTL laboratories and demonstrate that they meet the requirements. If these conditions are met, the CTF lab can issue CB reports together with the CBTL laboratory audit. The laboratory, which has completed TURKAK accreditation processes, can present TURKAK-approved reports in the market as accredited. A laboratory that met these accreditation and CB reporting requirements was not available in Turkey. In order to solve this problem in this thesis process, a study was conducted to establish an accredited laboratory in Turkey that could approve a li-ion battery to IEC62133-2, IEC62281, and EN50604 standard tests. Found at Vestel Electronics, this laboratory has successfully completed TURKAK accreditation audits. It also signed a CTF agreement with a CBTL laboratory. This Battery test laboratory can provide CB reports and TURKAK accredited reports. Battery approval tests have been performed in this laboratory. All test setups installed in this laboratory have been designed according to standard requirements. Standard requirements have been

analyzed, and appropriate test equipment has been created. The product can be tested with equipment that complies with the provisions of this standard. Test results of an E-bike project with test equipment setup and Battery management system (BMS) will be shared below parts. In this chapter, the reasons for starting the study, motivation and problem statement will be explained. In addition, the contribution of this study and the scope of the thesis will be stated.

1.1 Problem statement / Motivation

Battery systems began to have an important place in the world [3, 4]. Recently, studies have been performed for battery projects in Turkey. Factories are being established and there are many battery investment. Turkish investors want to develop the battery technology used in many products with R&D studies. In the next days, the battery will be of great importance in the world. Firms in Turkey have started important studies for this battery technology. There are many requirements such as production facilities, test-approval laboratories for these battery projects to be release on the field. New battery and cell factories are established in Turkey. Investments for these processes are increasing. But there are no laboratories that validate E-bike lithium-ion batteries. For produced batteries or cells should obtain approval certificates and then put on sale. These approvals are important requirements. Since there are no laboratories providing these approvals in Turkey, products are sent to foreign accredited laboratories for testing and approval. There are many disadvantages of carrying out these approval processes from foreign market. For example, the cell or battery for which R&D work is carried out needs to be shipped abroad. Since these products are not approved and their transportation is risky, many difficult transportation procedures occur. This long and difficult transportation process affects the project schedule. In the approval processes received from abroad, the R&D teams do not have a chance to immediately intervene in the problem that occurs during any

test. In addition, access to the results obtained during the tests is restricted. If the project schedules of the laboratories where the products are sent for testing are busy, the approval processes may be longer. These situations affect the approval schedules of the projects planned to be developed in Turkey. It is not possible to start the production of a product without validating the design and passing the approval tests successfully. As an important situation, it is necessary to perform these tests in accredited laboratories with appropriate devices. These tests are most appropriately performed in accredited laboratories. Accredited laboratories are those whose suitability has been audited. If the result of the tests required to bring the product to the market is successful, documents and certificates are prepared. Some of the procedures required for sales are these approval certificates and documents. CB reports are also required to launch products to the overseas market. CB reports state that the products are tested and approved according to IEC standards in an accredited laboratory. These CB reports can be obtained from CBTL laboratories that perform tests in accordance with IEC standards. A laboratory that met these accreditation and CB reporting requirements was not available in Turkey. In order to solve this problem in my thesis process, a study was conducted to establish an accredited laboratory in Turkey that could approve a lithium ion battery to IEC62133-2, IEC62281 and EN50604 standard tests. Battery approval tests are performed this laboratory.

1.2 Contribution

Establishing test laboratories for the developing battery technology in Turkey will be very beneficial for approval processes. Because, in case of failure of the product during approval, the possibilities of intervention and working on the fault will be accelerated. Approval processes will be more efficient. Having a laboratory with this competence in Turkey will speed up the approval processes and minimize the time

for product transportation. In this way, it will make a great contribution to the manufacturers for the approval processes. Laboratories in Turkey will also have a positive economic impact for approval processes. The contribution of this laboratory will be important in order to make the outputs of battery projects in our country more qualified and reliable. Especially for Turkish manufacturers, battery technology is a new study. The faster and under control it puts its products in safety and reliability tests, the more it will increase the quality of the product. Analyzing the product in the test processes will increase the design accuracy and the possibilities of finding solutions. Therefore, in order to solve this laboratory problem in my thesis, a laboratory study was carried out in which IEC62133-2 , IEC 62281(UN38.3- Transport standard) and EN50604 tests can be performed. In this laboratory, approvals and controls of lithium ion cells and batteries can be carried out. Devices conforming to standard tests were designed. Turkey's first E-bike battery project approvals were given in the laboratory. An important laboratory contribution has been provided for battery approval processes in Turkey.

1.3 Scope of Thesis

My thesis work was started to establish the first laboratory for lithium ion battery approvals in Turkey and to apply the approval tests for the IEC62133-2, IEC62281 and EN50604 standards and evaluate the outputs. If product designs meet testing requirements, they will need to be reported accredited. Accrediting the laboratory and making a CTF agreement are important goals. In line with this process, important processes in the product's release will be resolved. In addition, if the product has a BMS (battery management system), it will be one of the goals to control this card. First of all, this research will start by giving detailed information about the main idea of my thesis, what lithium ion cell and battery are, where, how and for what

purpose they are used and production processes. Information about the E-bike battery that has been tested will be given. The usage situations and areas of the tested E-bike batteries will be explained. Afterwards, examples from the usage areas of lithium ion cells and batteries, which are important technologies of the future, will be presented. BMS card functions used in e-bike batteries, their purpose and functions will be mentioned. The most important of the objectives of establishing a laboratory will be what the IEC standards are and their purpose. IEC62133-2, IEC62281 and EN50604 test requirements for e-bike approvals will be explained in detail. What will be applied for each test and how will the results be evaluated ? Requirements to be considered during the test will be explained. Functional safety logic and requirements for BMS card approvals will be summarized. The test results and all the information about the product will be collected and the details about the report writing required for approval will be explained. All product approval processes and required certification processes will be mentioned. Afterwards, the stages of laboratory setup will be started. What accreditation is and its importance will be explained. Information on why the CTF agreement is necessary and what it does will be provided. The features of all devices in the laboratory, how compliance checks are made and what the calibration is will be explained. The subject of why we should calibrate the devices will be mentioned. It will be explained how the layout was created and what attention was paid during the battery laboratory installation phase. Battery fire risks and precautions against them will be mentioned. IEC62133-2 , IEC62281(UN38.3) and EN50604 test results applied with E-bike will be reported and evaluations will be made about these results. Detailed test outputs and tables will be shared according to all standards. Information will be given about the results of open-short tests applied to the BMS card in the e-bike battery and why it is applied. In conclusion, the contributions of this laboratory work will be explained. A brief overview of which tests we can run and how we evaluate test outputs will be provided.

CHAPTER II

BATTERY SYSTEM

Battery systems are a structure consisting of cells and BMS[5]. There are many different cell structures and battery structures. In this chapter, information about the cell that makes up the battery will be given. Afterwards, the battery structure formed by the combination of cells will be specified. The E-bike battery structure that has been studied will be introduced. BMS, one of the most important parts for the battery, will be explained in detail. Briefly, This chapter will contain detailed information about cell, battery, E-bike battery, battery use cases and BMS.

2.1 What is the cell ?

There is a cell and battery management system card in the structure that makes up the batteries. Cells come together to form the battery system. Cells can form multiple structures by connecting them in series or parallel to the battery[6]. The task of the cells used in the battery is to convert chemical energy into electrical energy. Batteries consisting of cell are examined under 2 headings according to their rechargeable characteristics. They are specified as rechargeable (secondary) batteries and non-rechargeable batteries (primary)[7]. Cells have two electrode structures, anode and cathode[8].

2.2 What is the battery ?

Batteries are an assemblage of one or more cells whose chemical reactions generate a flow of electrons in a circuit. Batteries are used as an energy source. There are rechargeable (secondary) and non-rechargeable (primary) types of batteries [9]. Recently, li-ion batteries have been popularly used. Li-ion batteries can be used most

efficiently in terms of energy and weight, and therefore they have a long life. Li-ion can be molded in many different ways, which provides convenience to the designer [10]. Batteries are used in many fields. Significant examples are uninterruptible power supplies, electronic test equipment, toys, computer types, medical devices and electric vehicles, E-bike, etc.

2.3 What is the E-bike ?

One of the batteries that have an important place in the market is E-bike batteries. Lithium-containing e-bike batteries can be mounted on bicycles, providing the driver with more comfortable use. E-bike batteries supply energy to the motor on the bike and keep the bike moving. In this way, it gives the passenger to climb slopes more efficiently and travel more distance[11]. There are 36V- 48V etc. E-bike batteries in the market [12]. The battery model evaluated is nominal voltage 36V and application voltage 27V-42V in this study. Also, the capacity of this battery is 540Wh. The battery includes bluetooth, UV resistant structure, IP66 water proof features. This battery is attached to the frame of E-bikes. It has EN 50604-1, EN 62133-2, UN38.3 (IEC62281) and IP66 certificates.

2.4 Use cases

Nowadays, battery technology has developed significantly and is used in many areas. These areas are energy storage systems, aviation industry, medical devices, television, respiratory equipment, electric vehicles, uninterruptible power supplies, electronic devices, telephone, toys, computers, telecommunication systems, etc. [13, 14]. E-bike batteries will be evaluated in this project.

2.5 Battery management system (BMS)

The BMS is the system that manages the battery [15]. Controls battery operation, charge, and discharge. If the battery starts to pass outside the specified values, the

BMS immediately switches to protection mode[16]. These limits are always defined in the product specification. In our studies, meanwhile BMS improves the usage performance of each cell. It does this by making it work synchronously. Since it makes the working system of the battery efficient, it also increases its life. This system solves many safety problems such as overloading, explosion, and heating in the battery. It is the system that detects abnormal situations and manages the battery, and puts it in protection mode when necessary [17]. BMS board has many functions such as measurement and analysis, and protection. Each feature of these functions is described below [18, 19, 20].

1) Measurement and Analysis The measurement and analysis function of the BMS monitors several electrical measurements such as voltage, temperature, state-of-charge, state-of-health, current, maximum charging current, maximum discharge current, minimum/maximum voltage seen in cells or battery pack, energy consumed from first use, total run time from first use, number of charge-discharge cycles. The voltage of the package and the cells are essential to determine the battery's state of charge; therefore, the total voltage in the package, the voltage of a single cell, and minimum and maximum cell voltages are monitored through BMS. On the other hand, temperature represents the safety of the battery not exploding; therefore, average temperature, input temperature, output temperature, and the temperature of each cell are monitored[21]. State-of-charge is generally observed to understand how much energy is held in the battery. The state-of-health keeps track of the robustness of the package or any cell. Also, the input and output currents of batteries during charge/discharge processes are also monitored through BMS. In current monitoring, it is vital to have maximum charge current and maximum discharge current. The maximum charge and discharge currents are controlled by BMS. These maximum limits are stated explicitly in the product specification. BMS constantly checks these

values to prevent excessive current haulage. Batteries have nominal operating voltages and application voltage ranges. BMS controls the product according to these limits. Therefore, minimum/maximum voltage seen in cells or battery packs is measured by BMS. The energy consumed from the first use is monitored. The BMS system calculates the total working time from the first use. The estimated number of complete charge-discharge cycles is known after the batteries are manufactured. The BMS system monitors the number of charge-discharge cycles of the product for analysis of battery life.

2) Protection The BMS has many protection functions, such as prevention of high current withdrawal from batteries, the occurrence of high voltages during charging, the occurrence of low voltages throughout the discharge, high and low temperature, and the occurrence of leakage current. Therefore these functions ensure product safety. If a high current is withdrawn from the batteries, the product will increase in temperature. This increase creates an abnormal effect on the product, and there is a risk of explosion. Therefore the BMS system controls this feature and switches to protection mode in case of high current withdrawal. In case of high voltages during charging, the product becomes risky. For this reason, BMS puts the product in protection mode if the application voltage specified in the battery specification exceeds the max limit. If the occurrence of low voltages occurs throughout the discharge, the voltage balance of the system will be disturbed. Risky situations may occur, so BMS will put the product in protection mode. Many risks arise if high temperatures occur in the batteries. Many situations, such as explosion, burning, etc., may occur in the product. High temperatures also negatively affect battery life. Therefore, BMS should protect the product from high-temperature conditions. If lithium-ion batteries are affected by low temperatures, chemical reactions will be adversely affected. It will damage the operation of the product. BMS puts the product in a protection state so that the battery does not work at temperatures lower than the specification.

CHAPTER III

TEST REQUIREMENTS

In this chapter, information about the IEC standard will be given and its contributions will be explained. Afterwards, the necessary standards will be specified for an E-bike battery safety approval. Why these standards are needed and the decision criteria will be explained. Finally, IEC62133-2, IEC62281 and EN50604-1 standard tests and general requirements will be mentioned.

3.1 IEC standards

Founded in 1906, the International Electrotechnical Commission (IEC) is an international standards organization that prepares and publishes international standards for all electrical, electronic and related technologies[22]. IEC standards cover many electrical and electronic related fields. IEC standards provide guidance for the safety, reliability, performance, electromagnetic compatibility, design development and environmental impact of products. Thanks to IEC standards, electrical and electronic related technologies that will come into the field will be safer and well-designed. Thanks to IEC standards, product performances will rise to higher levels. There are committees that write the standards found in the IEC. These committees meet periodically. They revise the standards when necessary. Products designed in accordance with IEC standards will be more reliable and acceptable products in the market. In commercial processes, companies make transactions by taking the conformity of products to IEC standards as reference. For this reason, it is very important to make designs in accordance with IEC standards.

3.2 Test requirements of IEC standards for E-bike battery system

It is important to mention an E-bike standard first before the battery standards. EN 15194 standard is a standard specified for electric bicycles. This European Standard specifies requirements and test methods for these systems having a rated voltage up to and including 48 V dc or integrated battery charger with a nominal 230 V ac input. In other words, it references the necessary standards for e-bike batteries that do not exceed 48V. Also, according to this standard, the speed of this E-bike model should not exceed 25km/h. In line with this information, this standard states that tests in EN/IEC 62133-2 and EN 50604-1 standards are required for design safety verification. These two standards are used for E-bike battery approvals in E-bikes. IEC/EN 62133-2 standard cover secondary cells and batteries containing alkaline or other non-acid electrolytes safety requirements for portable sealed secondary cells, and batteries made from them, for use in mobile applications. The standard covering secondary lithium batteries used for light electric vehicle (EV) applications is EN50604. IEC62133-2 and EN50604 standards include tests to be applied with batteries. These tests are classified as mechanical, electrical, and environmental tests. Detailed information for the tests will be given in the following sections. In addition, carrying batteries is a risky situation. IEC62281 (UN38.3) is the standard that includes tests simulating the problems that may occur while the batteries are being transported. This standard comprises many test simulations of products such as storage, climbing to high altitudes, vibration, shock, etc. In summary, this IEC 62281(UN38.3) standard includes tests that simulate situations that products will encounter during transportation. Requirements and test results related to IEC62281 standard tests will be given in the following sections.

After the battery products are designed, tests must be performed for the reliability and safety of the design. Thanks to these tests, it is determined how reliable and

safe the product is. The risks that may occur before the products are released to the market are determined, and necessary corrections are made. Customers want the products which they will buy to be tested and reported in an accredited laboratory. In this case, the need to test products according to IEC / EN standards arises. In each of these standards, tests check the safety of the design. For these test requirements, the necessary setups should be established, and tests should be performed. For an E-bike battery approval, EN/IEC 62133-2, EN 50604, and IEC 62281(UN38.3) standards will be applied. According to these test requirements, the setup will be planned, and pass or fail test cases will be analyzed in the next section. In this section, the environmental, electrical, and mechanical test requirements of IEC62281, IEC 62133-2, and EN50604 standards will be explained.

3.2.1 IEC 62133-2 Tests

This significant standard specifies requirements and tests for the safe operation of secondary li-ion batteries & cells. Cells and batteries should be designed & planned to be safe & reliable under both intended use and reasonably foreseeable misuse. The purpose of this standard is to apply safety tests to prevent dangerous critical situations that may occur. The purpose of the tests is not only to provide safety; it is also important that the functions of the product continue. As it is known, risks can occur in cases where batteries are not designed safely and correctly. There are a lot of potential risks that may occur during the tests, such as leakage of cells electrolyte, explosion, fire, high temperatures, and rupture of a battery case. Also, there are important suggestions to guide the design in the standard. Some of these suggestions are for batteries consisting of cells or cell blocks connected in series, the capacities of the cells must be close to each other, of the same design, of the same chemistry, and from the same manufacturer. A battery management system should be used for batteries consisting of series-connected cells or cell blocks, etc. The standard includes

environmental, electrical, and mechanical tests. Some of these tests are applied to cells and some to batteries. IEC/EN 62133-2 tests are continuous charge, case stress, external short-circuit, freefall, thermal abuse, crush, overcharge, forced discharge, and mechanical (vibration & shock). A continuous charging test is applied with a constant current and voltage charging method. There is a test case stress test, which exposes the battery to high temperatures. The external short circuit test, which is one of the important tests, simulates a short circuit between the positive and negative terminals of the product. It is a free fall test that simulates a drop situation while the user is using the product. The thermal abuse test is an important environmental test that shows the risks when the cell reaches very high temperatures. In addition, a crash test is applied to see the effect that may occur on the cells in case of accident or jamming. There is a test for overcharging the battery for a long period. The reverse polarity state of the cell is a simulated forced discharge test. Lastly, there are mechanical tests that simulate shock and vibration situations that the product will encounter during transportation. As a result, if all tests of the product pass, the IEC62133-2 approval is successful.

3.2.2 IEC 62281 Tests

In this standard, there are tests simulating the risks that may occur during the transportation of lithium cells and batteries. It aims to send products safely during transportation. There are environmental, electrical, and mechanical tests performed with sequential cycles. In this standard, the same products are subjected to more than one test, and the results are evaluated in this way. These special series tests are altitude, thermal cycling, vibration, shock, and external short circuit tests. Potential risks that may occur during the tests are shifting, distortion, short-circuit, high temperature, leakage, venting, fire, rupture, and explosion.

IEC62281 standard has two parts for test conditions. The first part is the transport

tests. These tests are altitude, thermal cycling, vibration, shock, external short-circuit, and impact. The first five tests of these are performed as a sequential loop with the same samples. The second part is misuse tests. These tests are overcharge, forced discharge, and drop. There may be cases where the batteries are transported by plane. Therefore, it can be exposed to low-pressure environments. This low-pressure condition is simulated in the Altitude test. The thermal cycling test simulates storage conditions at high and low temperatures and thermal cycling between these lower and upper limits. In this way, the product is monitored at high and low temperatures. Conditions such as fire, explosion, and rupture should not occur. The product may be exposed to vibration and shock effects during transportation. Thanks to these vibration and shock tests, risks are observed. The external short circuit test simulates the risk of a short circuit to the product due to external influence. As a result of this test, extreme temperature increases, explosions, fire, etc., situations should not occur. Mechanical abuse is observed in the impact test. Internal short circuit conditions may occur as a result of the impact test. The overcharge test simulates how durable the product is to overcharge and what risks occur as a result of the test. As a result of this test, the product is controlled for a particular period of time. No fire or explosion is expected. The forced discharge test simulates what happens when a cell is forced discharged. It provides an understanding of how much the cell will be durable in this situation. A drop test, which may occur during the transportation of the products, is simulated. As a result, if the above test results are successful, the product can be given IEC62281 safety transport approval.

3.2.3 EN 50604 Tests

The standard is used for test procedures for voltage class A voltage class B type lithium-ion batteries. The voltage class A battery has a maximum working voltage equal to or less than 30 V a.c. (RMS) or equal or less than 60 V d.c) and voltage class

B battery has a maximum voltage of (greater 30 and equal or less 1000) V a.c. (RMS) or (greater 60 and equal or less 1500) V d.c.) removable li-ion battery (packages and) systems. This standard is important for observing the safety performance of the battery. Tests are not applicable for Li-ion cells. This significant standard specifies requirements and tests for the safe reliable operation of secondary li-ion batteries.

Standard provides design recommendations, and for Device Under Test (DUT), the situations that need attention during the tests are indicated. Also, indicates that the BMS board should be checked the battery. Standard provides an analysis of the protection states of the BMS card. The standard includes environmental, electrical, and mechanical tests. All tests are performed on a Lithium-ion battery. EN50604 standard tests are classified as mechanical (Vibration, Shock, Thermoplastic materials exposed to sunlight), climatic (Dewing, Thermal Cycling), simulated vehicle accidents (Crush, Water Immersion, Over-temperature, Under-temperature), electrical (Short Circuit), and system functionality (Overcharge protection, Loss of thermal control). Vibration and shock tests simulate situations that will occur during transportation. UV (ultraviolet) rays are applied to thermoplastic materials exposed to sunlight, and control is provided to see if there is a visual problem in the product. The dewing test is a test that simulates the risks that will occur in case of high humidity for the system and components. The thermal cycling test controls the temperature changes that the product will be exposed to. Also, crush situations that may occur in the event of an accident are controlled. The test that simulates the situation where the vehicle is flooded in water is the Water immersion test. The test is carried out by completely immersing the battery in water. High-temperature conditions that may occur while using or in storage are also monitored in this standard. In the low-temperature test, If the battery reaches a temperature less than the lower limit specified in the specification, it should stop charging. A short circuit situation is very risky for the battery. For this reason, the product should be short-circuited, and controls should

be provided to see if it is protected. In the overcharge protection test, it is checked whether the protection of the product is activated in case of overcharge. Lastly, It is the verification of the system that prevents the internal overheating that may occur in the product in the Loss of thermal control test. The working condition of this system is tested. As a result, if the tests on the product are successful due to all these controls, approval can be obtained from the EN50604 test.



CHAPTER IV

LABORATORY INSTALLATION PROCESS

The purpose of this chapter is the studies done in the laboratory setup processes. Accreditation studies and requirements will be explained. It will be conveyed that an accredited laboratory increases the accuracy of test results and is important for customers. How and why the CTF agreement was made and its processes will be explained. The accreditation and CTF agreement status of the established battery safety laboratory will be explained. Information about test equipment and calibration statuses will be given. Risks that may occur in battery tests will be evaluated. The test system and test area precautions taken against these risks will be explained in detail.

4.1 Accreditation

Accreditation is the process that provides proficiency checks by authorized bodies. Laboratory accreditation is obtained according to the ISO/IEC 17025 standard[23, 24]. According to this quality management standard, the accreditation compliance of the functioning of the laboratory is checked. At the same time, proficiency control of the laboratory is provided to the required technical standards. Accreditation requirements must have a quality management system in the laboratory, the devices used for testing must be calibrated, the personnel performing the standard tests must be competent, the laboratory environment conditions must meet the test requirements, there must be a system to control the products tested in the laboratory, the systems where the test results are stored must be organized, access to the laboratory is only should be provided by authorized personnel, etc. situations. In other words, in an accredited laboratory, conformity in terms of technique and management system must

be ensured . This established battery test laboratory has been audited by TURKAK according to ISO/IEC 17025 standards. As a result of the audit, competence was obtained. In addition, IEC62133-2, IEC62281 and EN50604 were realized in technical inspection. Competence has been achieved in terms of personnel and test equipment. Tests can be carried out in an accredited way in the laboratory. All instruments in the laboratory are calibrated. The personnel perform all the tests with these appropriate devices during the accreditation supervision and have to prove their competence. After the tests are carried out, they should be processed on the test result forms in the laboratory quality management system. At least 2 personnel should be competent in laboratories and test results should be checked by a second person[25]. The calibrations and intermediate controls of the devices should be followed continuously. The measurement accuracy of the tested devices is very important. The main purpose of an accredited laboratory is to obtain reliable results. The accreditation audit conducted by TURKAK was successfully completed. Accredited IEC62133-2, IEC62281 and EN50604 reports can be issued.

4.2 CTF agreement

In order to offer a CB certificate to customers who want a Certification Body certificate, it is necessary to be a CBTL laboratory approved by the IEC or to be a CTF laboratory inspected and authorized by CBTL laboratories. Therefore, it is necessary to make a CTF agreement with the CBTL laboratory to provide CB reports and certificates in accordance with IEC standards. CTF agreement has stage levels. These stages vary according to competencies. As long as the competent personnel prove themselves in the audits, they have the chance to reach the highest level stage. In these cases, CBTL inspections are reduced. An agreement was signed with a CBTL laboratory for the established battery laboratory. The CBTL organization audited the battery lab and staff competencies. In the audit, the quality system is also audited

by the CBTL organization. In this case, CTF compliance was obtained according to ISO/IEC 17025, IEC62133-2, IEC62281 and EN50604-1 standards. Reports and CB certificates prepared according to the tests carried out in the laboratory can be released to the market under the control of the CBTL laboratory. CTF stage transition processes are organized according to competence. In addition, CBTL laboratory inspects the laboratory once a year.

4.3 Test equipment and calibration

First of all, the devices in the laboratories should meet the standard requirements. Afterwards, all devices in the laboratory must be calibrated in accordance with Accreditation. In addition, intermediate controls should be made according to the calibration periods of the devices. The calibration process is very important for the device to give accurate results. One of the most important goals of accredited laboratories is to provide accurate and reliable results. It can provide this with equipment that has correct calibrated measurements. Therefore, all devices should be monitored regularly. All devices in the established laboratory have calibrations and a tracking system has been established. All equipment that can perform IEC62133-2, IEC62281 and EN50604-1 tests are available in the laboratory in a calibrated form. Exproof temperature and humidity chambers for environmental tests, battery and cell charge and discharge equipment, crush, impact, drop, vibration and shock mechanical equipment, electrical test setups, external short circuit chamber, and water immersion cabinet are available in the laboratory.

4.4 Laboratory layout that is fire durable and suitable for tests

Battery tests are dangerous and there is a risk of fire. Therefore, important precautions must be taken. In case of battery explosion, fire will be dangerous and its effect lasts for a long time. Therefore, it causes damage to the device and its surroundings.

Special studies have been carried out to minimize these risks. In the battery laboratory of the board, all rooms were separated from each other and the possibility of passing to other rooms was prevented even if a fire broke out. In this case, the fire will be able to be absorbed in a single room. Mechanisms were installed, most of which could be controlled from outside the room. In this way, the test personnel will be able to plan the test more safely. This section includes battery risks, fire durable test areas and systems. In addition, the precautions that can be taken during the tests will be mentioned.

4.4.1 Battery fire risks

Battery fire is more dangerous than other fires[26]. Every fire is risky, but it is very difficult to extinguish a battery fire. The reason for this is the chemicals used in the production of cells[27]. Therefore, important precautions should be taken in battery tests. Since it is very difficult to extinguish a fire that will occur, it will damage both the device and its surroundings. Toxic gases that will form as a result of fire are very dangerous[28, 29]. The size of the fire varies according to the amount of energy in the battery. After the fire is out, it continues until the energy is gone. Therefore, chemical gases and smoke will appear. If the devices are not fire resistant, the fire severity may increase even more. For this reason , all battery tested systems must be fire resistant . It should also be suitable for ventilation and safety in the environment. It is important that the personnel performing these tests are trained and specialized. The risks that will occur during the test are great. For this reason, systems that can be tested in the safest way should be established.

4.4.2 Fire durable test systems

Since the risk situations in the batteries are high, all equipment in the laboratory is designed to be fire resistant. The interior of the chambers is designed as ex-proof. It is in a structure that will dampen the explosion of the product inside. There

are openings to relieve the pressure that will occur in the explosion. Studies have been carried out to reduce the severity of explosion and fire. The equipment has been designed to minimize the risks that users will face during testing. Providing the controls and tests remotely is one of the most important precautions that can be taken against explosion or fire that may occur during the test. Special considerations for a few of the most dangerous tests will be discussed below.

The risk is high in the crush test. The crushed area was therefore created to be fire resistant. For the safety of the tester, the test cannot be started without closing the chamber cover. Controls are provided remotely. The control mechanism of the device is given in Figure 1 below. The product is placed in the crush chamber and then both the chamber door and the room door are closed. The test is started and controlled from the system installed outside the room. In this way, the personnel performing the test can be tested more safely.



Figure 1: Crush Test Setup & Control Panel

In the impact test, there is a risk of explosion and fire due to the weight dropped on the cell. For this reason, the surrounding of the impact cabinet is designed to be fire resistant. The pressure relief is opened. In addition, its front surface is covered with a special glass to observe the test. A metal barrier is placed in front of this glass and the risk is minimized. Impact test setup is given in Figure 2. After the setup is prepared, the cabin door and the room door are closed. The test can be done by controlling it outside. In this way, the personnel performing the test can be tested more safely.



Figure 2: Protected Impact Test Setup

The structures of all other setups are designed to be fire durable according to their risks. In summary, all devices are fireproof and separated by rooms. In the laboratory layout, all equipment is located in separate rooms. Controls can be provided externally. A design has been made considering the safety of the personnel performing the tests.

4.4.3 Fire durable test areas

While establishing this laboratory, primarily the risks in battery tests were evaluated. Studies were carried out to minimize the risks[30]. It was thought that these risks could be avoided if the laboratory was designed to be safe for fire and explosion. The risk that a battery may cause more damage to the environment and the device in case of explosion or fire, according to the battery energy, has been discussed. For this reason, the devices were placed in separate rooms and each room was designed with fire resistant walls to absorb the fire within itself. Even if there is a fire in the rooms, it will not be carried to other rooms thanks to the walls. The fire will continue until the energy of the battery is depleted and then the fire will go out. For this reason, this layout is planned to prevent damage to other devices or rooms. The walls separating the rooms are designed as several layers. Fire resistant structure has been formed. Extra security measures have been taken to create a protected zone for the external walls of the laboratory.

In Figure 3, there is a layout study of the laboratory that has been drawn. The room structure separated from each other is shown here. In this layout; There are crush room, impact test room, external short circuit room, climatic chamber rooms, altitude chamber room, water immersion room and mechanical room. Electrical tests are performed in the setups inside the device rooms. There are 3 emergency exit doors in this building. One of them is used for device input and output. One door is used for transitions between laboratories and offices. The emergency exit door in

the test area is planned for emergency escape situations that may occur during test observations.

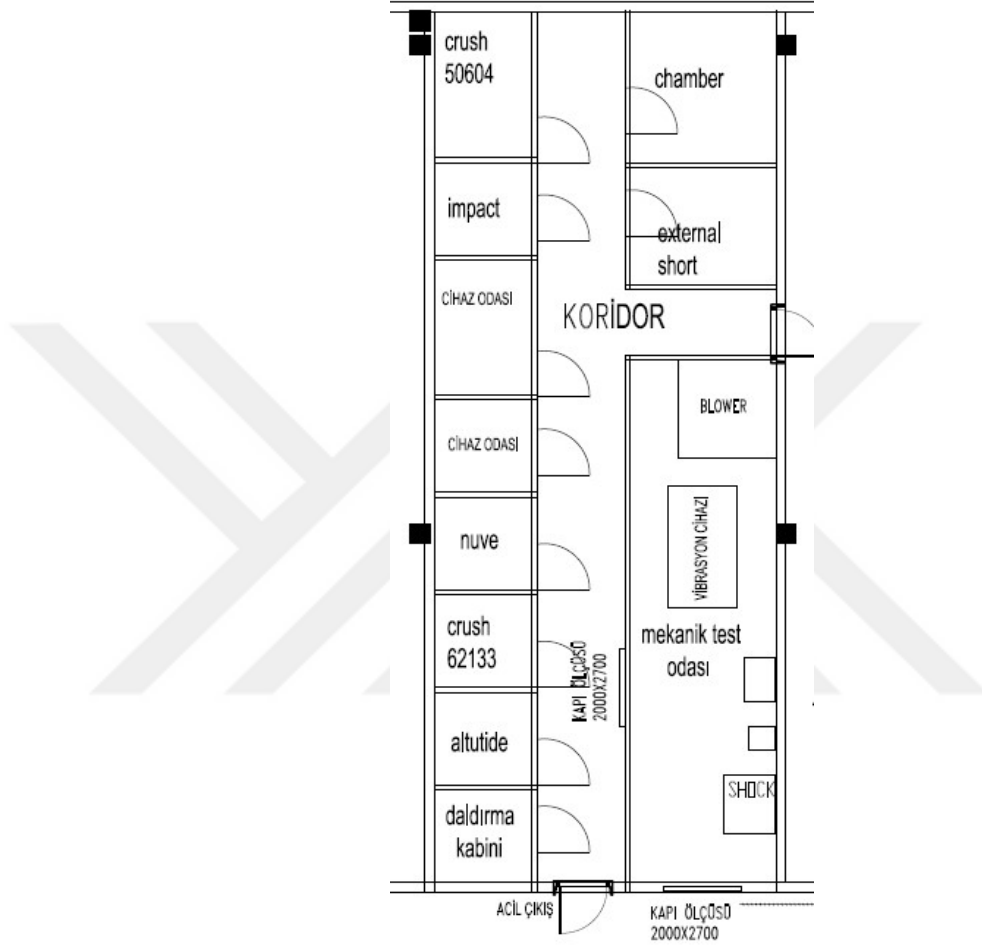


Figure 3: Laboratory layout

In Figure 4, there is a laboratory figure from the realized design. The laboratory was established with test rooms separated from each other. The floors are covered with ESD protected material. The doors of the rooms are resistant to fire and explosion. All rooms have emergency stop buttons. Mechanisms were installed outside the doors in order to control the tests from the corridor without entering the rooms. All rooms are named according to the devices. A regular structure has been established in accordance with accreditation.



Figure 4: Battery laboratory

There is a special ventilation system in the laboratory. In cases of fire, it evacuates the toxic smoke without passing it to other rooms. In this way, the room is protected from damage that may occur from fire. This ventilation system is available in all rooms. Pipe transitions between rooms are made in isolation. In the event of a fire, there will be no leakage to the adjacent rooms. Ventilation system in the vibration chamber is given in Figure 5. The ventilation system includes a suction and a fresh air blowing system. Fire resistant materials are used in ventilation pipes. In case of fire, it will be able to evacuate toxic gases and smokes.



Figure 5: Mechanical Room Ventilation System

In case of fire, there are emergency stop buttons outside each room to interrupt the electricity. Also, in extreme risk situations, a button has been added that will interrupt off the electricity of the entire laboratory from outside the laboratory. The battery may be in electrical testing at the time of fire. For this reason, it would be a better solution to cut off the electricity from outside and wait for the energy to run out. Emergency stop button of a room is given in Figure 6. As can be seen in the figure, each room has a separate fuse. With the emergency stop, the fuse opens and the energy is interrupted. The entire electrical bus line is externally connected to a single button. All electricity can be cut off with this button.



Figure 6: Emergency Stop Buttons for rooms

The laboratory is divided into rooms in case of fire. In addition, the outer walls of the entire laboratory are designed as a fire zone. Even if there is a fire, it will not be moved to the outside. Against these situations, fire resistant emergency exit doors have been placed in the laboratory. There are 3 emergency exit doors in the laboratory. All of these emergency exit doors are fire resistant. It is placed for emergencies that may occur in the test area. In extreme fire risks, the personnel may exit the laboratory through the emergency exit doors and interrupt the electricity from the outside. One of the emergency exit doors is given in Figure 7. Also, as can be seen in the figure, all safety systems in the laboratory are marked with signboards. It have been placed for emergency exit doors, fire extinguishers, etc. Necessary precautions have been taken for occupational health and safety in the laboratory. Apart from the safety precautions planned for the battery, it is also critical for occupational health precautions.

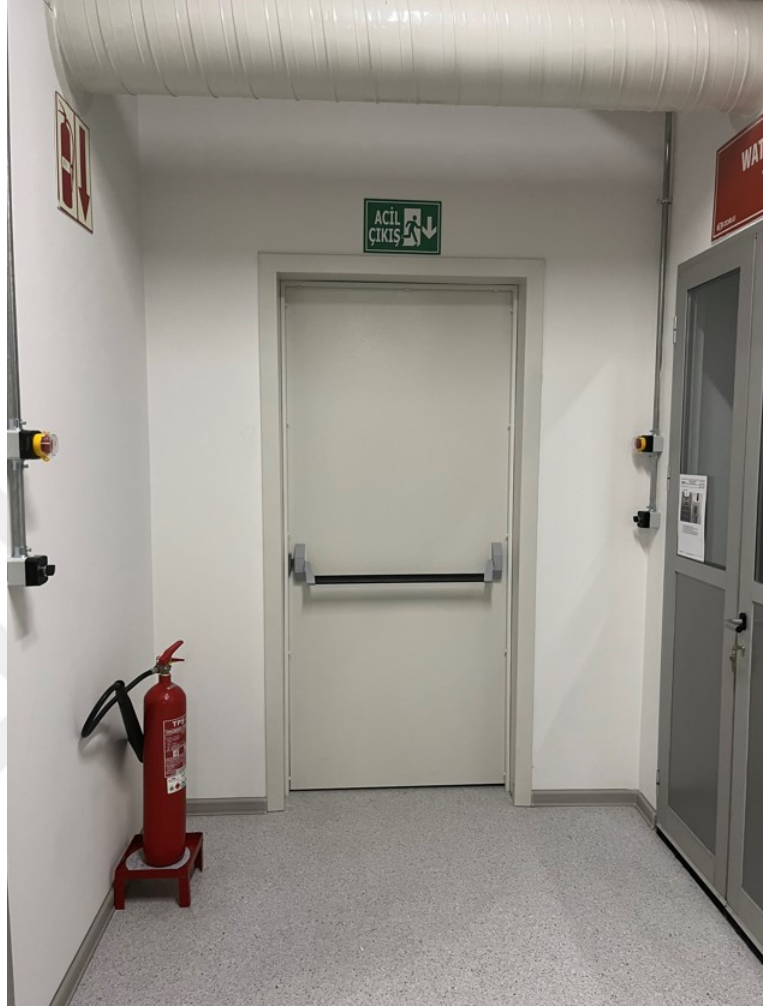


Figure 7: Emergency Exit

In summary, all rooms in the laboratory are separated from each other. Special ventilation system and emergency stop buttons have been installed to cut the electricity. For personnel safety, remote control of tests and laboratory emergency exit doors have been implemented in the laboratory.

In addition, personnel should wear special fire resistant clothing and gloves when performing the tests. Special masks should be used during the intervention against toxic gases that may occur in case of fire.

CHAPTER V

E-BIKE BATTERY TEST RESULTS

For E-bike battery safety approvals, tests according to IEC standards should be applied. These tests should be performed with setups designed in accordance with standard requirements. In this chapter, information will be given about the setups installed according to the test requirements of IEC62133-2, IEC62281 and EN50604-1. In addition, the test results performed to the E-bike battery according to these standards will be shared. Results will be evaluated against standard requirements. If all safety tests of the battery are successful, the design will be approved. In addition, why open-short is performed to the BMS system in the E-bike battery and the results will be explained.

5.1 IEC 62133-2 Test Results

The IEC62133-2 standard is performed to secondary cells and batteries containing lithium ion. The sample E-bike referenced in this study is the battery. This standard is required within this battery approval. The standard includes electrical, mechanical and environmental tests. The tests to be explained below are Continuous charging at constant voltage (cells), Case stress at high ambient temperature (battery), External short-circuit (cell), External short-circuit (battery), Free fall, Thermal abuse (cells), Crush (cells), Over-charging of battery, Forced discharge (cells), Vibration, Mechanical shock.

5.1.1 Continuous charging at constant voltage (cells)

This test simulates continuous charge at constant voltage. The risks that may occur in case of continuous charging are observed. Charged cells are charged according to

the values specified in the specification during a certain period. Explosion and fire conditions should not occur in the battery during its charge. The chamber and cell charge equipment used for the test are given in Figure 8. Charging cables are connected to the cells inside the chamber. The charging process is carried out in the exproof chamber. Also, the cells in the exproof chamber are given in Figure 9



Figure 8: Continuous charging at constant voltage (cells) Test Setup

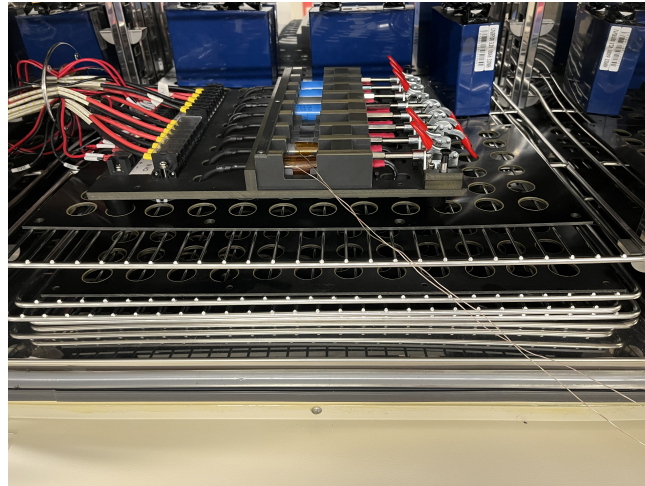


Figure 9: Exproof Chamber & Cell Holder

In Table 1, the results of the continuous charging at constant voltage test applied

for 5 samples are given. There are recommended charge voltage and current values in the table. The open circuit voltage(OCV) value measured before the test is also indicated.

Table 1: Continuous charging at constant voltage (cells)

Sample no	Recommended charging voltage Vc (Vdc)	Recommended charging current Irec (A)	OCV before test (Vdc)	Results
Cell 1	4.25	4.9	4.19	NF,NE,NL
Cell 2	4.25	4.9	4.19	NF,NE,NL
Cell 3	4.25	4.9	4.19	NF,NE,NL
Cell 4	4.25	4.9	4.19	NF,NE,NL
Cell 5	4.25	4.9	4.19	NF,NE,NL

5.1.2 Case stress at high ambient temperature (battery)

This test is performed if the battery has an enclosure. Aim of this test, The components inside the product should not be exposed to high temperatures while using the product. This test does not apply to batteries without an enclosure. Because the product is tested in high temperature chambers. The products are placed in the environmental chamber. Rechargeable batteries are exposed to high temperature in order to evaluate the enclosure condition. The batteries remain in the chamber for a certain time specified in the standard. It is then removed from the chamber and observed. As a test result, Physical problem should not observed at the battery case, internal protective components and cells. In the test study, Case stress at high ambient temperature test was performed to 3 products. No problem was observed in the E-bike batteries that were tested. Test results are evaluated as Pass. It meets the requirements of the after test required standard.

For the case stress test, the E-bike battery is placed in a chamber set at high temperature. This high temperature chamber and battery are given in figure 10.



Figure 10: Case stress Test Setup

5.1.3 External short-circuit (cell)

This test is especially performed to the cells inside the battery separately. In other words, the short circuit status of the cell is evaluated separately. This test simulates a short circuit between the positive and negative terminals of a fully charged cell. Observe what will happen in this abnormal situation. There must be no fire and explosion. In some short circuit tests, it is necessary to place the battery or cell in different ambient temperatures. An ex-proof environmental chamber is planned to provide these ambient temperatures. A resistor with suitable ohm values is connected to the cell from outside and the short circuit condition is simulated. The test of the product continues according to the periods and conditions specified in the standard. There will be no fire or explosion during this time. Test results performed to E-bike batteries will be given in the tables below. In addition, the cells used in the test are charged and put to the test. Cells are divided into 2 different groups while being charged. As those charged at high temperature and those charged at low temperatures.

In Tables 2 and 3, the external short circuit test results of the cells are given. In Table 2 , the results of cells charged at upper limits are given. In Table 3 , the

results of cells charged at lower limits are given. Tables include ambient temperatures, pre-test OCV values, maximum case temperature rise value and results.

Table 2: External Short Circuit (Cell)

Sample charged at charging temperature upper limit 50°C				
Sample no	Ambient T(°C)	OCV before test (Vdc)	Maximum case temperature rise (K)	Results
Cell 1	55C	4.22	51	NF,NE
Cell 2	55C	4.22	36.3	NF,NE
Cell 3	55C	4.22	34.7	NF,NE
Cell 4	55C	4.22	42.8	NF,NE
Cell 5	55C	4.22	42.3	NF,NE

Table 3: External Short Circuit (Cell)

Sample charged at charging temperature lower limit -5°C				
Sample no	Ambient T(°C)	OCV before test (Vdc)	Maximum case temperature rise T (K)	Results
Cell 1	55C	4.17	40.4	NF,NE
Cell 2	55C	4.17	36.3	NF,NE
Cell 3	55C	4.17	39.2	NF,NE
Cell 4	55C	4.17	42.8	NF,NE
Cell 5	55C	4.17	42.3	NF,NE

E-bike battery cell in exproof external short circuit chamber is given in Figure 11 with its positive and negative poles connected.

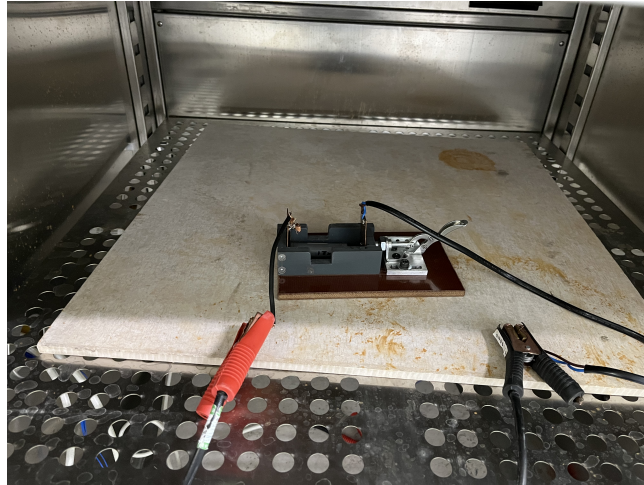


Figure 11: External Short Circuit (Cell) Test Setup

5.1.4 External short-circuit (battery)

This test simulates a short circuit between the positive and negative terminals of a fully charged battery. Observe what will happen in this abnormal situation. There must be no fire and explosion. In some short circuit tests, it is necessary to place the battery or cell in different ambient temperatures. An ex-proof environmental chamber is planned to provide these ambient temperatures. A mechanism is established in this chamber to short-circuit the terminals of the battery or cell. This shorting is controlled externally by a switched system for security. A short circuit is a risky situation. For this reason, the system is established with an ex-proof chamber. Figure 12 is an external short circuit setup installed in an ex-proof chamber. The connection cables in this setup are connected to the positive and negative terminals of the product. The product is placed inside the ex-proof chamber. Then the chamber is closed. The test is carried out with the short circuit switch on the chamber interface.



Figure 12: External Short Circuit Test Setup & Exproof chamber

External short circuit test results are given in Table 4. This test result format complies with IEC62133-2. In this form, how many samples are tested and sample

names are given. In this test result form, the ambient value where the test was performed, the resistance value used for the test, the voltages measured in the products after the test, and the temperature rise values are given. If all results are successful, the product passes the external short circuit test.

Table 4: External short-circuit (battery)

Sample no	Ambient T($^{\circ}$ C)	OCV before test (Vdc)	Maximum case temperature rise $\delta T(K)$	Component single fault condition	Results
Battery 1	23	41,142	0	-	NF,NE
Battery 2	23	41,140	0	1	NF,NE
Battery 3	23	41,135	0	2	NF,NE
Battery 4	23	41,138	0	3	NF,NE
Battery 5	23	41,143	0	4	NF,NE
Battery 6	23	41,135	0	5	NF,NE

Supplementary information: - No fire or explosion - Others (please explain):

Battery short-circuit without single faulted components on protective circuit (BMS) Mosfets on protective circuit (Q6, Q7, Q9, Q10) reacted immediately. Battery normally functional after the test after enabling the output with pushing the button.

Battery short-circuit with components single faulted on protective circuit (BMS):

- 1) Short circuit of mosfet Q6 (S-D pins) – Mosfets on protective circuit (Q7, Q9, Q10) reacted immediately. Battery normally functional after the test after enabling the output with pushing the button
- 2) Short circuit of mosfet Q9 (S-D pins) – Mosfets on protective circuit (Q7, Q6, Q10) reacted immediately. Battery normally functional after the test after enabling the output with pushing the button
- 3) Short circuit of mosfet Q7 (S-D pins) – Fuse U2 reacted immediately, no voltage on battery outlets after the test. Battery damaged after the test
- 4) Short circuit of mosfet Q10 (S-D pins) – Fuse U2 reacted immediately, no voltage on battery outlets after the test. Battery damaged after the test
- 5.) Bridging the fuse U2 - Mosfets on protective circuit (Q6, Q7, Q9, Q10) reacted immediately. Battery normally functional after the test after enabling the output

with pushing the button.

5.1.5 Free fall

The purpose of the test is to observe whether an explosion or fire occurs when a cell or battery is dropped from heights in reasonable use. Charged cells or batteries are dropped from a certain height to a concrete floor in the number of times specified by the standard. In this way, the user's battery drop situations will be tested. It is necessary to install a setup that will simulate the worst case. This setup will be controllable from outside the room by switched. Since there is a danger of explosion when the battery or cell falls, it will be risky to have the person doing the test in the environment. Therefore control will be provided remotely. This system, which will be the system that keeps the product at a certain height in the test setup, will be controlled with a switch and remote testing will be possible thanks to this switch. Free fall will be provided from the system holding the product and the product will be dropped on a concrete floor. In this case, the durable of the battery in case of falling will be observed. After the test is performed to the batteries or cells, control should be provided for a certain period of time. Afterwards, there should be no fire or explosion in the product. As a result of the test applied to the E-bike batteries, there was no deformation, explosion or fire situation in the products. The test result was evaluated as a pass.

The free fall test setup is given in the figure 13 below. The height from the floor has been calibrated to the standard requirements of this device. The rail system holding the product is controlled from the outside with the switch. This rail system opens to simulate the product being dropped. The product falls on the concrete floor. The product should be placed in such a way that it falls to the floor in worse conditions.



Figure 13: Free Fall Test Setup

5.1.6 Thermal abuse (cells)

This test is only performed to cells. Extremely high temperatures are simulated in this test. This extreme temperature should not cause fire and explosion in the cells. Charged cells are placed in chambers set to over temperature. The chamber rises to the extreme temperature limits at a certain rate. Afterwards, the product is kept at this extreme temperature limit value for the time required in the standard. As a result of this test, there should be no explosion and fire situations.

5.1.7 Crush (cells)

In the IEC 62133-2 standard, the crush test is only performed to cells. Rigorous crushing of a cell is simulated. Each fully charged cell is placed in the crush tester. There are two flat surfaces in the crushing area of the crush equipment. The cell is crushed according to the force value specified in the standard. When the crushing force is applied at maximum or there is a certain level of voltage drop, the crushing process is stopped. In this test, there should be no explosion or fire in the cells.

In addition, force perform positions can be changed according to cell types. The position is selected according to the cell type and the cells are placed in the crushing area accordingly. Cell types are cylindrical, prismatic and coin cell.

A crush cell test setup, as shown in Figure 14, can be designed such that two metal plates are placed horizontally with a space in between. The battery is seated on the lower metal plate, and the upper plate is moved downwards. The temperature monitoring of the cell is followed by an externally connected thermocouple.



Figure 14: Crush Test Setup

The crush test results performed to the cells used for the e-bike are given in the table 5 and table 6 below. In this tables, there are OCV before cell test, OCV at removal of crushing force, maximum force applied to cell during crush(kN). In Table 5, the results of cells charged at upper limits are given. In Table 6, the results of cells charged at lower limits are given. As a result of these crush tests applied to Cell, no problem was observed. The test result can be considered as "Pass".

Table 5: Crush Test (Cell)

Sample charged at charging temperature upper limit 50°C				
Sample no	OCV before test (Vdc)	OCV at removal of crushing force	Maximum force applied to the cell during crush(kN)	Results
Cell 1	4.22	4.22	13	NF,NE
Cell 2	4.22	4.22	13	NF,NE
Cell 3	4.22	4.22	13	NF,NE
Cell 4	4.22	4.22	13	NF,NE
Cell 5	4.22	4.22	13	NF,NE

Table 6: Crush Test (Cell)

Sample charged at charging temperature lower limit -5°C				
Sample no	OCV before test (Vdc)	OCV at removal of crushing force	Maximum force applied to the cell during crush(kN)	Results
Cell 1	4.15	4.15	13	NF,NE
Cell 2	4.15	4.15	13	NF,NE
Cell 3	4.16	4.16	13	NF,NE
Cell 4	4.15	4.15	13	NF,NE
Cell 5	4.15	4.15	13	NF,NE

5.1.8 Over-charging of battery

Battery manufacturers provide information about the use cases of their products in the specifications. In this information, the charging time is also indicated. This test simulates charging for a longer time than specified in the specification. There should be no fire or fire during this test. Products are charged at constant current. While charging, the supply voltage is increased. These supply voltage values are adjusted from the battery charge-discharge equipment according to the standard requirements. The temperature changes of each battery should be monitored. Fire and explosion conditions should not be observed in the test.

In Figure 15, the overcharge test setup performed to the E-bike battery is given. Testing can be performed with charge equipment and battery. The test is evaluated by overcharging the battery according to the standard and manufacturer spec values.

Overcharging test results performed to E-bike Batteries are given in Table 7. The constant charging current is set to 30 A while performing the test. Also, the supply voltage value is set to 51.6 Vdc. Sample information, OCV before charging, total charging time (minutes), maximum case temperature and success status of the results are given in the table. Total charging time was shown as *.

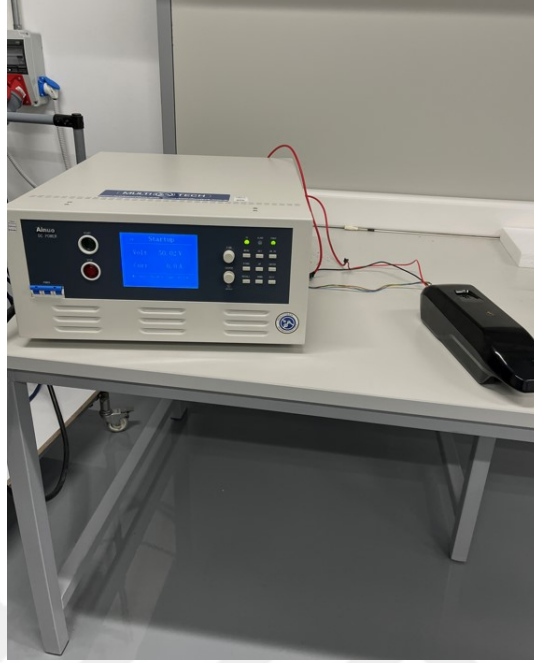


Figure 15: Overcharge Test Setup

The reason of this, Batteries are charging for few seconds, then the protection circuit (BMS) reacts, interrupting the charging. Batteries were left in charging state for 24h.

Table 7: Over-charging of battery

Sample no	OCV before charging (Vdc)	Total charging time (minute)	Maximum outer case temperature (C)	Result
Battery 1	30,236	*	25,1	NF,NE
Battery 2	30,321	*	25,2	NF,NE
Battery 3	30,223	*	24,6	NF,NE
Battery 4	30,510	*	24,8	NF,NE
Battery 5	30,136	*	24,6	NF,NE

5.1.9 Forced discharge (cells)

A cell must withstand a reverse polarity condition. When this reverse polarity situation occurs, explosion or fire should not occur. The cell is discharged by being discharged process up to the lower limits specified in the specification. Afterwards, it is discharged forcibly with the current given in the standard up to the negative limits specified in the specification. The discharge process continues for a certain period

of time. Forced discharge test set applied with DC supply and electronic is given in figure 16. It is placed in the holder to provide easy access to the cell positive and negative poles. A multimeter is used to measure cell voltage.

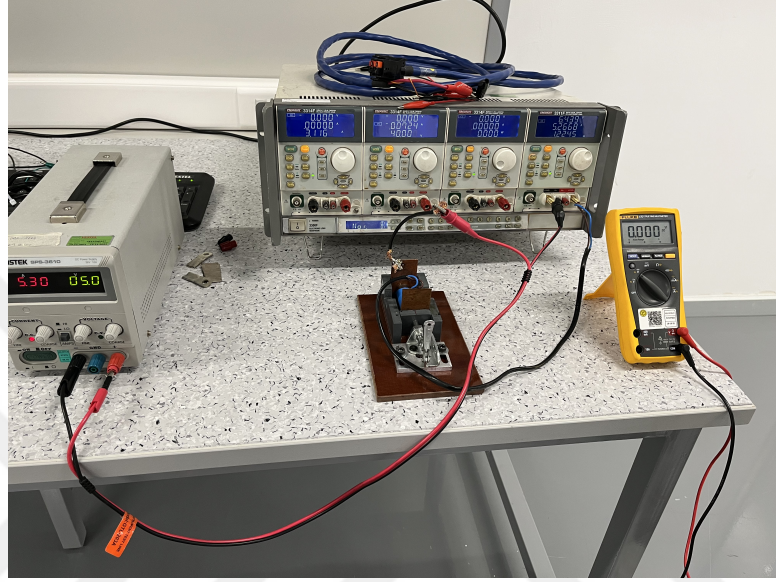


Figure 16: Forced discharge cell Test Setup

E-bike cell forced discharge test results are given in the table 8 below. No fire or explosion was observed in the test. The measurements made in the test results are listed in the table below. This table includes product numbers, OCV before application of reverse charge (Vdc) values, Measured reverse charge(mA) values, Lower limit discharge voltage(Vdc) values and results.

Table 8: Forced discharge (cells)

Sample no	OCV before application of reverse charge (Vdc)	Measured reverse charge(mA)	Lower limit discharge voltage(Vdc)	Result
Cell 1	3,00	4900	2.5	NF,NE
Cell 2	2,98	4900	2.5	NF,NE
Cell 3	3,00	4900	2.5	NF,NE
Cell 4	3,00	4900	2.5	NF,NE
Cell 5	3,00	4900	2.5	NF,NE

5.1.10 Vibration

2 mechanical tests are applied to the batteries in accordance with IEC62133-2 standard. One of them is the vibration test. The purpose of this test is to simulate the vibration conditions that the product will be exposed to in transportation and use situations. There should be no leakage, fire or explosion in the battery exposed to vibration. In order to perform the tests, a setup must be established that can provide the G value and frequency values specified by the standard. Afterwards, the product is firmly connected to the vibration table with product jigs. After the connection is made, the product is exposed to the vibration cycles required by the standard. The test is applied to all axes of the product. This vibration cycle is programmed from the vibration equipment interface. Vibration cycle images will be given in Figure 17 below.

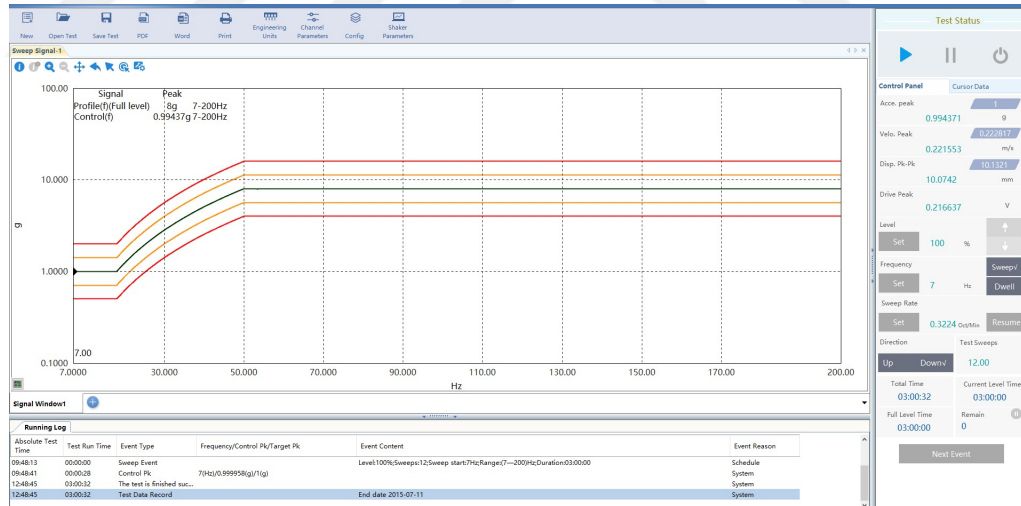


Figure 17: Vibration Test Output from Interface

Vibration test results applied to E-bike batteries are as in table 9. While evaluating the vibration test results, leakage, fire and explosion conditions are evaluated. As given in Table 9, the OCV measurement of the product is made before and after the test. In addition, mass measurements are made before and after the test. In this

way, controls are provided to determine whether the products have function controls and malfunctions.

Table 9: Vibration Test Result

Sample no	OCV before test (Vdc)	OCV after test (Vdc)	Mass before test (g)	Mass after test (g)	Result
Battery 1	40,572	40,570	2823,2	2821,4	NF,NE, NR, NL, NV
Battery 2	40,521	40,513	2821,9	2820,9	NF,NE, NR, NL, NV
Battery 3	40,621	40,618	2824,0	2822,8	NF,NE, NR, NL, NV

E-bike battery connected to vibration bench with jigs is given in setup figure 18. This vibration machine can perform 3-axis testing. Connections are made with jigs according to the axes and tests are performed in 3 axes.

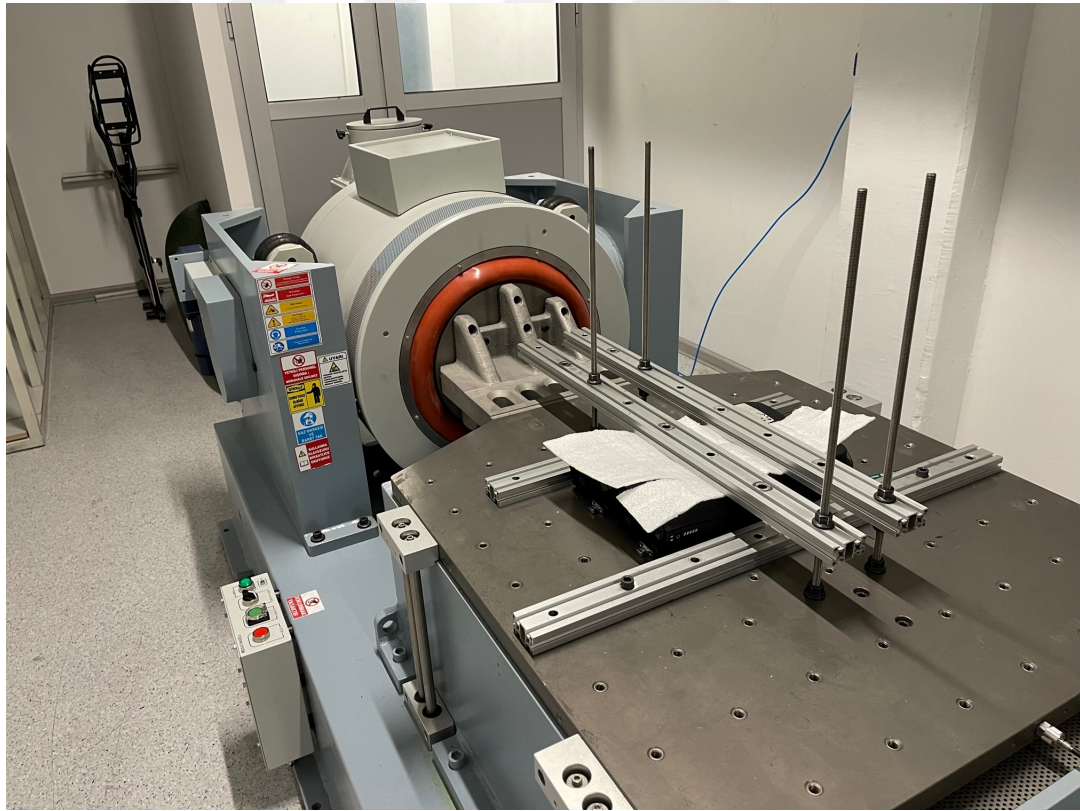


Figure 18: Vibration Test Setup

5.1.11 Mechanical shock

The other mechanical test applied to the batteries in the IEC 62133-2 standard is the shock test. This shock test simulates rough handling during transport and use situations. There should be no leakage, fire or explosion in the battery exposed to shock. In order to perform the tests, a setup should be established that can apply the G value specified by the standard with the desired pulse duration. Afterwards, the product is firmly attached to the shock table with product jigs. After the connection is made, the product is exposed to the shock impact that the standard requires. The test is applied to all axes of the product. This shock pulse is programmed from the interface of the equipment. Shock impact images will be given in figure 19 below.

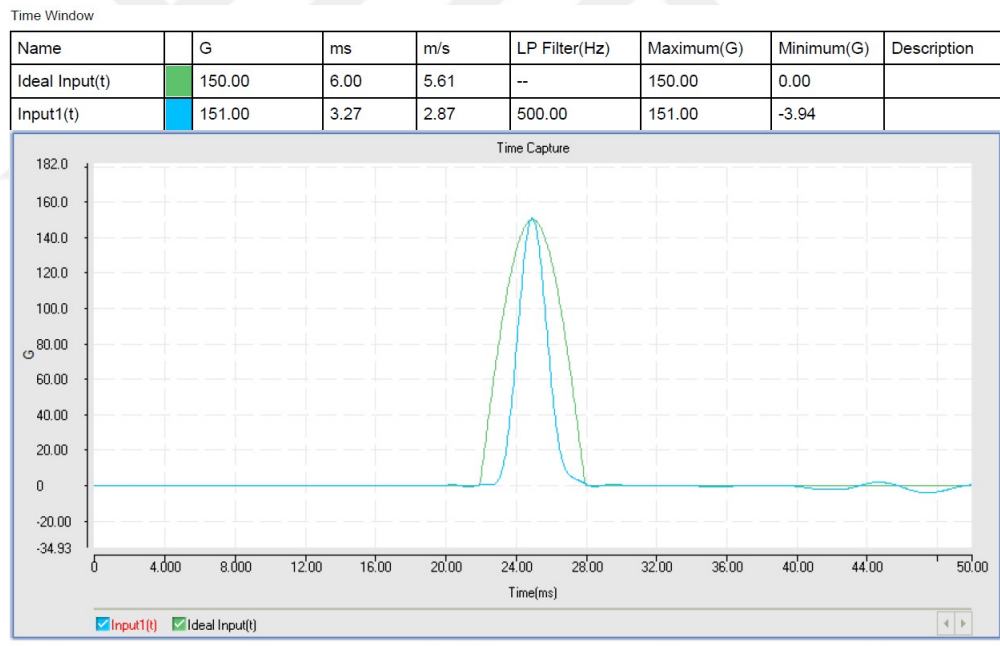


Figure 19: Shock Test Output from Interface

Shock test results performed to E-bike batteries are as in table 10. Tests are applied to the product as much as specified by the standard. E-bike samples are prepared for shock testing. While evaluating the shock test results, leakage, fire and explosion conditions are evaluated. As given in Table 10, the OCV measurement of the product

is made before and after the test. In addition, mass measurements are made before and after the test. In this way, controls are provided to determine whether the products have function controls and malfunctions.

Table 10: Shock Test

Sample no	OCV before test (Vdc)	OCV after test (Vdc)	Mass before test (Vdc)	Mass after test (Vdc)	Result
Battery 1	40,725	40,723	2823,0	2823,0	NF,NE, NR, NL, NV
Battery 2	40,802	40,792	2822,4	2822,3	NF,NE, NR, NL, NV
Battery 3	40,654	40,648	2822,6	2822,4	NF,NE, NR, NL, NV

The test equipment given in figure 20 was made to comply with these test requirements. In addition, calibrations of shock test equipment were made. It meets the test requirements. The product is firmly fixed on the table of this test equipment thanks to the jig. Shock test is applied to all axes. The equipment has a rail system. In this structure, the product is raised to the upper levels together with the table. Afterwards, the test is started from the control interface next to the device. Since the handling situation will be simulated, the product is suddenly dropped on a hard floor that will create a shock impact. Thanks to the sensors here, it shows how many G forces are applied to the product and how long it takes. In this way, it is checked that equipment meets the standard requirements. Afterwards, the product was checked after the test. No problem was observed in the applied test. The test result was completed successfully.

IEC62133-2 approval tests are completed with the shock test. If the battery and cell pass all tests successfully, IEC62133-2 approval can be given to the E-bike project. E-bike batteries and cells in this study passed the IEC62133-2 tests successfully. The design meets the safety tests of this standard. Safety approval can be given. In addition, reports and certificates can be prepared for sales.

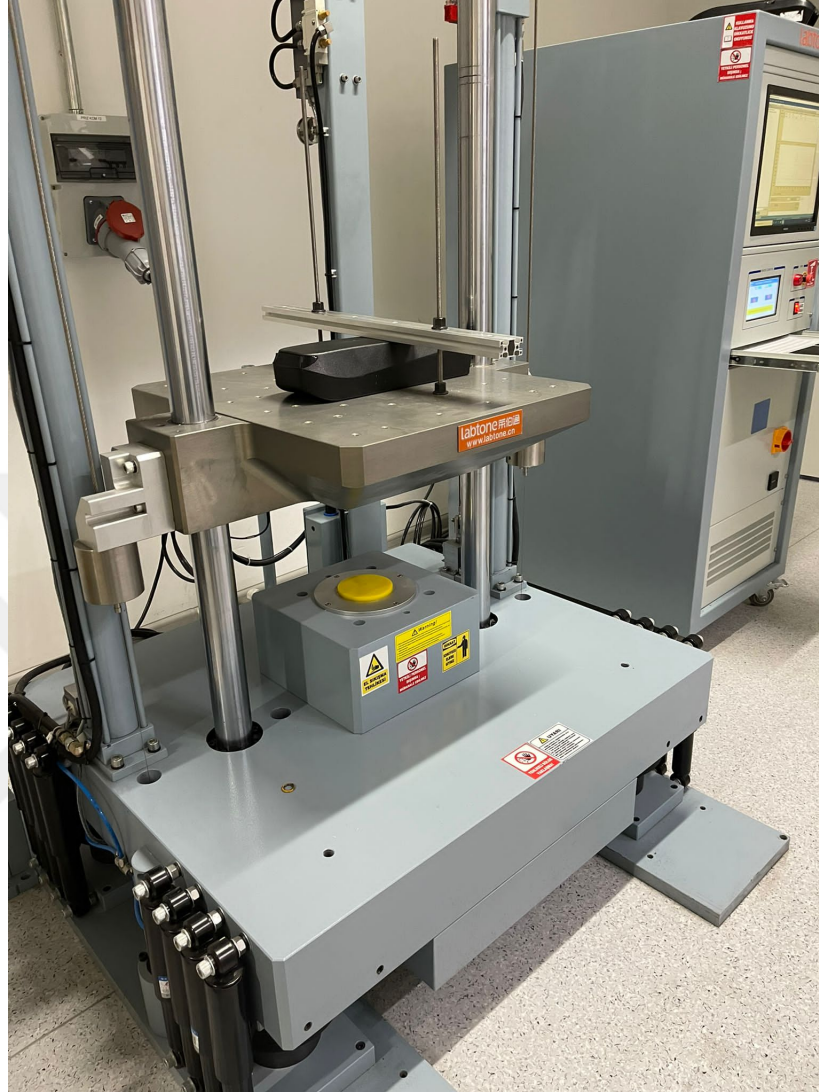


Figure 20: Shock Test Setup

5.2 IEC 62281 Test Results

The IEC62281 standard is performed to secondary-primary cells and batteries for transportation process. The sample E-bike used in this study is the battery. This standard is required within this battery approval. The standard includes electrical, mechanical and environmental tests. The tests to be explained below are altitude, thermal cycling, vibration, shock, external short circuit, impact, overcharge, forced discharge, drop test.

5.2.1 Altitude

The IEC62281 standard evaluates the transport conditions of the battery. Batteries can be transferred by air transport as well as road transport. So, there may be cases where the batteries are transported by plane. Therefore, it can be exposed to low-pressure environments. This low-pressure condition is simulated in the Altitude test. This altitude test can simulate air transport under low pressure conditions.

This test is the initial test of the IEC 62281 sequential tests. For this test, required product is added in the test plan as much as the standard requirement. The necessary precondition (charge cycle) is applied to these products. Afterwards, the products are placed in a specially designed altitude chamber. This chamber is equipment that can provide low pressure to simulate air transport. Products placed in this altitude chamber simulate the transport situation within the chamber for a certain period of time. There should be no leakage, no venting, no short circuit, no fire or explosion during the test. In the first 5 sequential of tests to be specified in the IEC 62281 standard, the mass and OCV values of the products are measured before and after the test. The mass and voltage losses that will be affected by these tests should not exceed the limits determined by the standard. In addition, there is a lighting system in the chamber as seen in the figure.

The altitude simulation test chamber is given in Figure 21. This chamber is designed as explosion and fire durable. It simulates the low pressures to which the products will be exposed during air transport. The equipment has a necessary interface to adjust the chamber indoor pressure to low pressures. As the pressure in the chamber will decrease when the test starts, it is tightly locked to the mechanism after placing the product. Each contact with the outside is cut off. There is also an emergency stop button in the product against emergencies. The test can be stopped and started with the remote control. Explosion-proof glass is designed for the chamber to observe the product from the outside.



Figure 21: Altitude Test Setup

E-bike battery altitude test results are given in Table 11. This table contains sample no, preconditions of samples, OCV before and after test, Mass before and after test, Mass loss, Mass loss limit values. As a result of the measurements and tests, the altitude test result was evaluated as Pass. Fire, explosion, rupture or short circuit conditions were not observed during the test.

Table 11: E-bike Altitude Test Result

Sample no	Precondition	OCV before test (V)	Mass before test (g)	OCV after test (V)	Mass after test (g)	Mass loss	Mass loss limit	Result
Battery 1	25 Cycles	41,085	2822,41	40,933	2822,29	0	0,1	PASS
Battery 2	25 Cycles	41,081	2821,87	40,954	2821,74	0	0,1	PASS
Battery 3	25 Cycles	41,140	2821,10	40,984	2821,04	0	0,1	PASS
Battery 4	25 Cycles	41,131	2825,03	40,984	2824,99	0	0,1	PASS
Battery 5	1 Cycles	41,561	2822,15	41,290	2822,10	0	0,1	PASS
Battery 6	1 Cycles	40,761	2822,52	40,682	2822,44	0	0,1	PASS
Battery 7	1 Cycles	41,092	2821,34	41,001	2821,26	0	0,1	PASS
Battery 8	1 Cycles	40,772	2826,12	40,694	2826,06	0	0,1	PASS

5.2.2 Thermal cycling

This test simulates the states of cells and batteries being affected by temperature changes that may occur during use or storage. The test is carried out according to the temperature cycles specified in the standard. The aim is to observe the situations that will occur when the product encounters low and high temperatures. These temperature transitions occur in short periods of time. Temperatures are performed in a continuous cycle between high and low limits. Products are placed in a exproof chamber. Then this cycle program is entered into the chamber interface, the test is started. The temperature transitions in the chamber can be controlled simultaneously from the interface. The chambers have been calibrated and the temperature values applied in the chamber have been verified with the value displayed on the interface. These situations are critical due to accreditation. In addition, although the product transitions quickly between the lower and upper limits, the storage situation at the lower and upper limit values is simulated as long time. At these limit points, the waiting times are longer as specified by the standard. In summary, thanks to this test, we can observe the risks that may occur both in case of rapid temperature changes and in the case of storage. During the test, situations such as fire, explosion, short circuit, rupture should not occur in the product. This test is the 2nd of the IEC62281 sequential tests. Therefore, the samples used in the 1st test should be used in this test. This is very important for evaluation.

The exproof temperature and humidity chamber where the temperature cycling tests are applied is given in Figure 22. The product is placed in this chamber and then the thermal cycling program, which is programmed from the interface, is started. This is how the test is applied. The program here will run as long as the standard requirement. During the working process, temperature changes will occur and this situation will be analyzed. Simultaneously, the changes can be followed from the control unit.



Figure 22: Temperature Cycling Test Setup

E-bike battery thermal cycling test results are given in Table 12. This table contains sample no, preconditions of samples, OCV before and after test, mass before and after test, mass loss, mass loss limit values. As a result of the measurements and tests, the thermal cycling test result was evaluated as Pass. Fire, explosion, rupture or short circuit conditions were not observed during the test.

Table 12: E-bike Thermal cycling Test Result

Sample no	Precondition	OCV before test (V)	Mass before test (g)	OCV after test (V)	Mass after test (g)	Mass loss	Mass loss limit	Result
Battery 1	25 Cycles	40,933	2822,29	40,460	2820,18	-0,07	0,1	PASS
Battery 2	25 Cycles	40,954	2821,74	40,481	2820,01	-0,06	0,1	PASS
Battery 3	25 Cycles	40,984	2821,04	40,491	2820,11	-0,03	0,1	PASS
Battery 4	25 Cycles	40,984	2824,99	40,486	2823,14	-0,07	0,1	PASS
Battery 5	1 Cycles	41,290	2822,10	40,853	2820,23	-0,07	0,1	PASS
Battery 6	1 Cycles	40,682	2822,44	40,393	2820,35	-0,07	0,1	PASS
Battery 7	1 Cycles	41,001	2821,26	39,902	2819,89	-0,05	0,1	PASS
Battery 8	1 Cycles	40,694	2826,06	40,407	2825,32	-0,03	0,1	PASS

5.2.3 Vibration

This test is the 3rd of the IEC62281 sequential tests. Therefore, the samples used in the 2nd test should be used in this test. This is important for test sequencing. The purpose of this test is to simulate the vibration conditions that the product will be exposed to in transportation and use situations. There should be no leakage, fire, explosion, short circuit or rupture in the battery exposed to vibration. In order to perform the tests, a setup must be established that can provide the G value and frequency values specified by the standard. Afterwards, the product is firmly connected to the vibration table with product jigs. After the connection is made, the product is exposed to the vibration cycles required by the standard. The test is applied to all axes of the product. This vibration cycle is programmed from the vibration equipment interface. The vibration test requirements in the IEC62281 transport standard are the same as the vibration test in the IEC62133-2 standard.

E-bike battery vibration test results are given in Table 13. Controls were provided before and after the test. Also, this table contains sample no, preconditions of samples, OCV before and after test, mass before and after test, mass loss, mass loss limit values. As a result of the measurements and tests, the vibration test result was evaluated as Pass. Fire, explosion, rupture or short circuit conditions were not observed during the test. The products whose test is completed are taken to the next test. The next test is the shock test, which is another mechanical test.

Table 13: E-bike Vibration Test Result

Sample no	Precondition	OCV before test (V)	Mass before test (g)	OCV after test (V)	Mass after test (g)	Mass loss	Mass loss limit	Result
Battery 1	25 Cycles	40,460	2820,18	40,400	2819,26	-0,03	0,1	PASS
Battery 2	25 Cycles	40,481	2820,01	40,421	2819,22	-0,03	0,1	PASS
Battery 3	25 Cycles	40,491	2820,11	40,482	2819,16	-0,03	0,1	PASS
Battery 4	25 Cycles	40,486	2823,14	40,455	2822,55	-0,02	0,1	PASS
Battery 5	1 Cycles	40,853	2820,23	40,836	2819,74	-0,02	0,1	PASS
Battery 6	1 Cycles	40,393	2820,35	40,377	2819,25	-0,04	0,1	PASS
Battery 7	1 Cycles	39,902	2819,89	39,835	2818,75	-0,04	0,1	PASS
Battery 8	1 Cycles	40,407	2825,32	40,356	2825,10	-0,01	0,1	PASS

The vibration test setup in the IEC62281 standard performed for the e-bike battery is given in figure 23. The product is attached to the vibration bench with jigs. The loop which is a standard requirement, write to interface program and start.

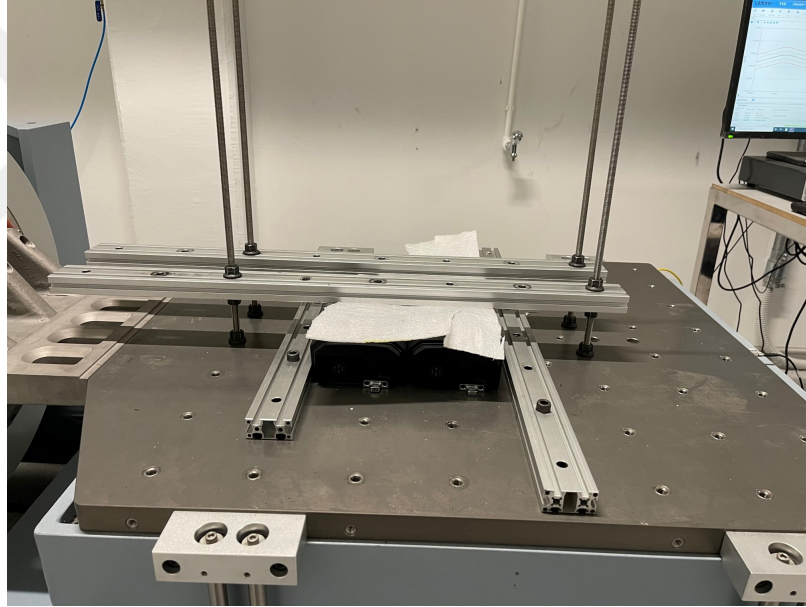


Figure 23: Vibration Test Setup

5.2.4 Shock

This test is the 4th of the IEC62281 sequential tests. Therefore, the samples used in the 3rd test should be used in this test. The functionality of the products to be used in the test must be intact. This shock test simulates rough handling during transport and use situations. There should be no leakage, no fire, no explosion, no short circuit or no rupture in the battery exposed to shock. In order to perform the tests, a setup

should be established that can apply the G value specified by the standard with the desired pulse duration. Afterwards, the product is firmly attached to the shock table with product jigs. After the connection is made, the product is exposed to the shock impact that the standard requires. The test is performed to all axes of the product. This shock pulse is programmed from the interface of the equipment. The shock test requirements in the IEC62281 transport standard are the same as the shock test in the IEC62133-2 standard.

E-bike battery shock test results are given in Table 14. This table contains sample no, preconditions of samples, OCV before and after test, Mass before and after test, Mass loss, Mass loss limit values. As a result of the measurements and tests, the shock test result was evaluated as Pass. Fire, explosion, rupture or short circuit conditions were not observed during the test.

Table 14: E-bike Shock Test Result

Sample no	Precondition	OCV before test (V)	Mass before test (g)	OCV after test (V)	Mass after test (g)	Mass loss	Mass loss limit	Result
Battery 1	25 Cycles	40,400	2819,26	40,393	2819,26	-0,01	0,1	PASS
Battery 2	25 Cycles	40,421	2819,22	40,439	2819,04	-0,01	0,1	PASS
Battery 3	25 Cycles	40,482	2819,16	40,481	2818,84	-0,01	0,1	PASS
Battery 4	25 Cycles	40,455	2822,55	40,453	2822,32	-0,01	0,1	PASS
Battery 5	1 Cycles	40,836	2819,74	40,834	2819,55	-0,01	0,1	PASS
Battery 6	1 Cycles	40,377	2819,25	40,378	2819,01	-0,01	0,1	PASS
Battery 7	1 Cycles	39,835	2818,75	39,8325	2818,45	-0,01	0,1	PASS
Battery 8	1 Cycles	40,356	2825,10	40,355	2824,87	-0,01	0,1	PASS

5.2.5 External short-circuit

This test is the last of the IEC62281 sequential tests. Therefore, the samples used in the 4th test should be used in this test. External short circuit situation is a risky situation. Therefore, in this test, the risks that may occur in case of external short circuit are analyzed. During this test, there should be no situations such as overheating, fire, explosion and rupture. Since abnormal situations may occur, the product is placed in a protected temperature chamber. The temperature required by the standard is set and the chamber is closed. Then, against the risk of explosion and

fire, the short circuit operation is performed from the interface of the ex proof short circuit chamber (from outside of chamber). The positive and negative terminals of the product placed in the chamber are connected to the switch system in this setup. A low value external resistor is added to this product output. Afterwards, the short circuit situation is simulated and the risks are observed.

E-bike battery tests are carried out in the chamber of external short circuit protection given in figure 24. The chamber is durable fire and explosion. The sample is placed in this chamber. The sample is connected to the short circuit switch in the chamber. The setup is established so that the sample outputs are connected to the positive and negative terminals. Afterwards, test controls can be made with the interface outside the chamber.



Figure 24: External Short Circuit Chamber Test Setup

The external short test, which is the last of the IEC62281 sequential tests, was applied to the battery. The results are given in table 15. This table contains sample

no, preconditions of samples, OCV before and after test, maximum case temperature values. As a result of the measurements and tests, the external short circuit result was evaluated as Pass. Fire, explosion, rupture, short circuit or excess temperature conditions were not observed during the test.

Table 15: External short circuit Test Result

Sample no	Precondition	OCV before test (V)	OCV after test (V)	Maximum case temperature	Result
Battery 1	25 Cycles	41,015	40,995	55,8	PASS
Battery 2	25 Cycles	40,955	40,950	56,2	PASS
Battery 3	25 Cycles	41,011	41,010	55,3	PASS
Battery 4	25 Cycles	41,012	41,010	55,7	PASS
Battery 5	1 Cycles	41,143	41,140	54,8	PASS
Battery 6	1 Cycles	40,984	40,982	55,4	PASS
Battery 7	1 Cycles	41,014	41,010	54,9	PASS
Battery 8	1 Cycles	41,001	39,989	55,7	PASS

5.2.6 Impact

There are cells in E-bike batteries. This test is a mechanical impact test that will cause an internal short-circuit condition. A special mechanical structure should be designed for this test. In order to apply the impact, the necessary kilograms and dimensions should be designed. A frictionless shooting setup is made to simulate a test with this weight. This weight is dropped on the cell from the height specified by the standard, and the impact situation is simulated. However, before dropping, a cylinder stick of special raw material is placed on the cell. After creating this system, the test is performed. The internal short-circuit situation that may occur in the event of an impact is analyzed. As a result of the test, there should be no overheating, explosion, or fire in the cell. These criteria continue to be checked for a certain period after the test.

Figure 25 shows the Impact test setup. There is a magnetic system that holds the weight here. This magnetic system drops the weight on the cell from the specified height without friction. This release process is controlled by an external switch. The

cell is placed on the ground, and a cylindrical stick is placed on it. This stick must be on the product during the test. As can be seen in the figure 25, there is a structure that allows the weight to fall almost without friction. The magnetic system drops the weight directly on the cell thanks to this structure.



Figure 25: Impact Test Setup

After the test is performed, observation is made for a certain period of time. If the temperature becomes stable in the cell, the impact setup door is opened and the final state is observed. The state of the cell after the test is given in figure 26. Although the product was damaged, it did not experience excessive heat, explosion and fire did not occur. After observing this situation for a certain time specified in the standard, approval can be given for the test.

Cells are preconditioned according to standard requirements before testing. Thus,



Figure 26: Status after impact test

samples prepared according to standard requirements are tested. Impact test results performed to cells are given in table 16. Multimeter and datalogger were used while taking test measurements. Voltage values are measured before test with multimeter. Case temperature values are monitored with a datalogger. This process is provided by connecting a thermocouple. This table contains sample no, preconditions of samples, OCV before and maximum case temperature values. As a result of the measurements and tests, the impact test result was evaluated as Pass. Fire, explosion, short circuit or excess temperature conditions were not observed during the test.

Table 16: Impact Test Result

Sample no	Precondition	OCV before test (V)	Maximum case temperature (g)	Result
Cell 1	25 Cycled Cells	3,581	22,8	PASS
Cell 2	25 Cycled Cells	3,582	23,1	PASS
Cell 3	25 Cycled Cells	3,581	22,6	PASS
Cell 4	25 Cycled Cells	3,581	22,7	PASS
Cell 5	25 Cycled Cells	3,581	23,0	PASS
Cell 6	1 Cycled cells	3,581	23,4	PASS
Cell 7	1 Cycled cells	3,582	23,1	PASS
Cell 8	1 Cycled cells	3,581	22,6	PASS
Cell 9	1 Cycled cells	3,582	22,7	PASS
Cell 10	1 Cycled cells	3,581	23,2	PASS

5.2.7 Overcharge

This test simulates the risks of overcharging the battery. Manufacturers arrange a specification that includes maximum limits for their products. It recommends the use of the product within these limits. In this test, more current and voltage values than the upper limit specified in the specification will be performed to the product. In this case, observation is made for abnormal situation risk will occur in the product. As an additional note, if the product exceeds the limits specified in the specification, it is usually protected if the product has a BMS. There should be no fire or explosion during the test. In addition, after the test, observation should be made to see if there will be a problem with the product for a certain period of time.

The results of overcharge performed to E-bike batteries are given in the table 17 below. This table contains sample no, preconditions of samples, OCV before test, maximum charging current , maximum charging voltage, total charging time values. As a result of the measurements and tests, the overcharge test result was evaluated as Pass. Fire and explosion were not observed during the test. During the test, Batteries are charging for few seconds, then the protection circuit (BMS) reacts, interrupting the charging.

Table 17: Overcharge Test Result

Sample no	Precondition	OCV before test (V)	Maximum charging current(mA)	Maximum charging voltage(V)	Total charging time	Result
Battery 1	25 Cycles	41,012	8000	50,4	1 day	PASS
Battery 2	25 Cycles	40,897	8000	50,4	1 day	PASS
Battery 3	25 Cycles	41,004	8000	50,4	1 day	PASS
Battery 4	25 Cycles	41,004	8000	50,4	1 day	PASS
Battery 5	1 Cycles	41,041	8000	50,4	1 day	PASS
Battery 6	1 Cycles	40,987	8000	50,4	1 day	PASS
Battery 7	1 Cycles	41,025	8000	50,4	1 day	PASS
Battery 8	1 Cycles	41,007	8000	50,4	1 day	PASS

5.2.8 Forced discharge

Forced discharge test simulates the risks that may occur in case of forced discharge of cells. The setup is installed with electronic load and dc power source. The cells are then forcibly discharged. An example circuit diagram describing this setup system is given in figure 27 below. The electronic load constant in this circuit is taken in resistance(CR) mode and its positive end is connected to the positive end of the cell. The negative terminal is connected to the negative terminal of the DC power source. Finally, the positive terminal of the DC power source is connected to the negative terminal of the cell. The DC power source operates in constant current(CC) mode.

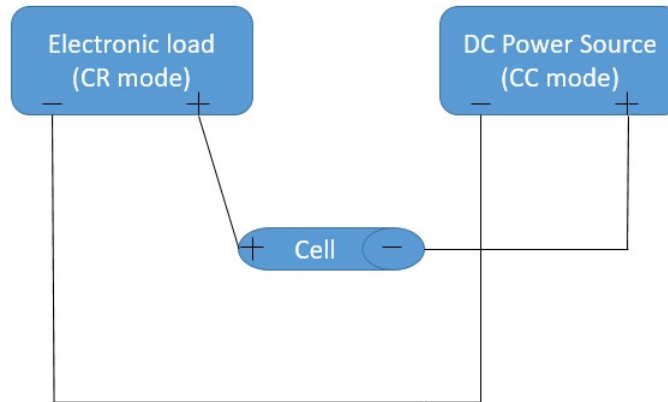


Figure 27: Forced Discharge Test System

E-bike battery forced discharge test results are given in Table 18. This table contains sample no, preconditions of samples, OCV before test, measured reverse charging current (mA), total time for reversed charging application (min) values. As a result of the measurements and tests, the forced discharge test result was evaluated as Pass. Fire and explosion conditions were not observed during the test.

Table 18: Forced Discharge Test Result

Sample no	Precondition	OCV before test (V)	Measured reverse charging current (mA)	Total time for reversed charging application (min)	Result
Cell 1	1 Cycles	3,022	9800	30	PASS
Cell 2	1 Cycles	3,021	9800	30	PASS
Cell 3	1 Cycles	2,989	9800	30	PASS
Cell 4	1 Cycles	2,994	9800	30	PASS
Cell 5	1 Cycles	3,007	9800	30	PASS
Cell 6	1 Cycles	3,014	9800	30	PASS
Cell 7	1 Cycles	3,041	9800	30	PASS
Cell 8	1 Cycles	3,025	9800	30	PASS
Cell 9	1 Cycles	3,041	9800	30	PASS
Cell 10	25 Cycles	3,055	9800	30	PASS
Cell 11	25 Cycles	2,974	9800	30	PASS
Cell 12	25 Cycles	3,000	9800	30	PASS
Cell 13	25 Cycles	3,016	9800	30	PASS
Cell 14	25 Cycles	3,011	9800	30	PASS
Cell 15	25 Cycles	3,024	9800	30	PASS
Cell 16	25 Cycles	2,984	9800	30	PASS
Cell 17	25 Cycles	2,959	9800	30	PASS
Cell 18	25 Cycles	3,014	9800	30	PASS
Cell 19	25 Cycles	3,019	9800	30	PASS
Cell 20	25 Cycles	3,015	9800	30	PASS

5.2.9 Drop test

A rough handling situation can occur when transporting a package full of cells or batteries. Problems may occur with products due to rough handling. The drop test assesses this risk. A package full of product is dropped from the height specified by the standard to a concrete floor. During this test, conditions such as extreme temperature, fire, explosion, short circuit and ventilation should not occur on the products.

This test was applied with a package containing E-bike batteries. As a result of the test, no problems were observed in the products.

5.3 EN 50604 Test Results

The EN 50604-1 standard is performed to secondary lithium batteries used in light EV (electric vehicle). These standard tests apply to the battery only. Provides battery approvals. The standard includes electrical, mechanical and environmental tests. The tests to be explained below are vibration, shock, drop, dewing, thermal shock cycling, crush, water immersion, over temperature condition, under temperature test, short circuit, overcharge protection.

5.3.1 Vibration

This test simulates the durability and safety performance of the battery against vibration conditions that it may be exposed to in normal use. The battery vibration test in EN50604 has only one difference from the vibration test in IEC62133-2 and IEC62281 standards. Except for this difference, the procedures are the same. This difference, in the EN50604 vibration test, while the product is in vibration, the supplier will be discharged up to the minimum discharge voltage with the maximum continuous discharge current recommended by the supplier. For testing, the products must be mounted on a vibration shaker bench. Vibration setup should meet all g value and frequencies that are standard requirements. There should be no fire, explosion, leakage or battery enclosure rupture in the product during and after the test.

In the E-bike battery vibration test, the products were firmly mounted on the vibration shaker bench. EN50604 test requirements were programmed from the vibration device's interface. This program contains the necessary G value and frequency cycles. Simultaneously, a discharge setup is established for the product. The recommended maximum discharge current of the tested e-bike battery was 20A and the minimum voltage value in case of discharge is (End Voltage) 28.0 Vdc (when first cell reaches 2.8 Vdc). In other words, when a cell value reaches 2.8Vdc, the discharge mode will be interrupted. There are 10 cells in the E-bike battery. The minimum

recommended voltage is 28.0Vdc. In this case, the minimum value for a single cell is 2.8Vdc. During and after the test, the product did not experience any fire, explosion, leakage or battery enclosure rupture. In this case, the test result was evaluated as "pass".

5.3.2 Shock

This test simulates the durability and safety performance of the battery against shock conditions (sudden brake and driving over road bumps or pot holes) that it may be exposed to in normal use. Thanks to this shock test, we can observe the risks that may occur in case of shock impacts. EN 50604 shock test requirements are the same as the shock tests in IEC 62281 and IEC 62133-2 standards. For testing, the products must be mounted on a shock bench. Shock setup should meet all g value and pulse duration that are standard requirements. There should be no fire, explosion, leakage or battery enclosure rupture in the product during and after the test.

In the E-bike battery shock test, the products were firmly mounted on the shock bench. EN50604 test requirements were programmed from the shock device's interface as pulse duration and g values. This program contains the necessary G value and pulse duration. During and after the test, the product did not experience any fire, explosion, leakage or battery enclosure rupture. In this case, the test result was evaluated as "pass"

The test equipment given in figure 28 was made to comply with these test requirements. The product is firmly fixed on the bench of this test equipment thanks to the jig. The equipment has a rail system. In this structure, the product is raised to the upper levels together with the bench of shock. Afterwards, the test is started from the control interface of shock equipment. Since the handling situation will be simulated, the product is suddenly dropped on a hard floor that will make required a shock impact. Thanks to the sensors here, it shows how many G forces are applied

to the product and how long it takes(pulse duration). In this way, it is checked that equipment meets the standard requirements. Afterwards, the product was checked after the test. No problem was observed in the applied test.



Figure 28: Shock Test Setup

5.3.3 Drop

The purpose of the drop test is to simulate the user accidentally dropping the battery in cases of removal, replacement and repair. In the case of this drop, the mechanical impact to be performed to the product may reveal risks. In the drop test, the product

is kept in the climatic chamber for a certain period of time and then charged. Then, the samples will be ready for testing. The products are dropped from the height specified by the standard to concrete floor as a certain number . The products should be placed in the drop system in such a way as to provide the worst condition. The product is observed during and after the test. There should be no fire, explosion, leakage or rupture.

The climatic chamber is set to -10 degrees and the E-bike battery is placed in the chamber. The product remained in the chamber for a certain period of time. Afterwards, the product was removed and charging was performed. The drop test was performed to observe the last worst condition. As a result of the test, no leakage, fire, explosion or rupture was observed. Test result was evaluated as "Pass".

5.3.4 Dewing (Temperature change)

This test simulates the use of the system/component under high ambient humidity. It allows us to test the high humidity and temperature conditions that the product can experience in the market. This test applies to battery packs and systems. In Summary, it simulates possible climatic deterioration situations during the service life of battery packs and systems. In Figure 29, there is an E-bike battery placed in the climatic chamber. Dewing test is performed to this battery. A humidity and temperature program with standard requirements has been created for the interface in front of the chamber. With this interface, the test is controlled. The E-bike battery placed in the exroof temperature and humidity chamber has been subjected to the dewing test requirements of EN50604-1. A dewing cycle has been applied to the battery for a certain period of time. In other words, the product has encountered humidity and temperature changes. At the end of the cycle, no problems were observed when the product was removed from the chamber and controls were provided. E-bike battery dewing test result is evaluated as "PASS".



Figure 29: Dewing Test Setup

Since the information of the standard is confidential, data in temperature and humidity graphs cannot be shared in detail. For this reason, Figure 30 has been added to show the temperature and humidity transitions. In this part, temperature and humidity transitions with standard requirements are applied to the product. There are maximum/minimum settings for humidity and temperature in the interface. In addition, detailed test programming has been done in the interface

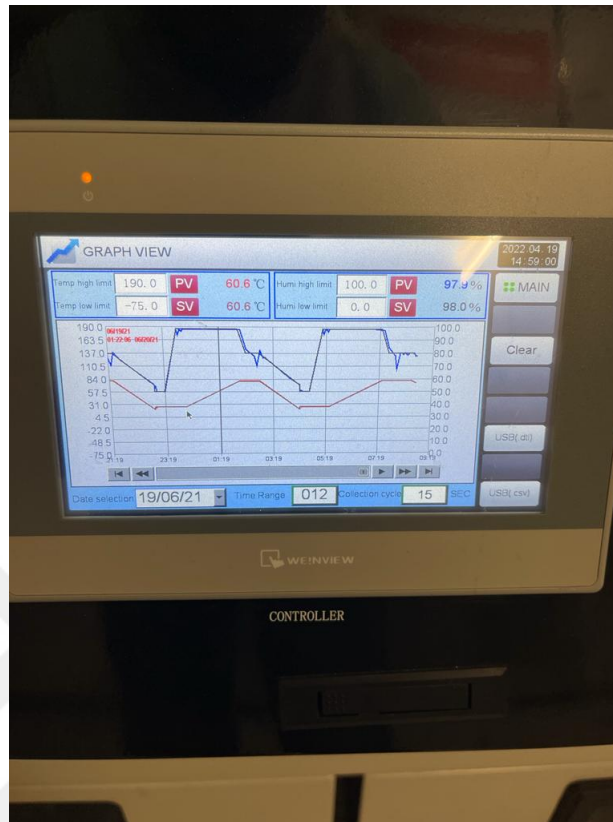


Figure 30: Dewing Test Setup Interface

5.3.5 Thermal shock cycling

Thermal shock cycling test simulates durability to sudden temperature changes. It is a test performed to observe all temperature changes that the product will encounter throughout its life. The product will expose to a certain number of cycle tests between low and high temperatures. Potential electrical and mechanical failures that may occur will be problems caused by rapid temperature changes. These problems will be analyzed in the thermal shock cycling test and necessary precautions will be taken. During the test, the product is placed in a protected temperature chamber. The product is exposed to cycles between the low and high temperature limits specified in the standard. During the test, it will be constantly monitored to see if there is any damage to the product. Voltage and temperature will be checked. As a result of testing, all functions of the product should work as designed, both during and after

testing.

In E-bike thermal shock cycling tests, the products are placed in a exproof temperature chamber. The required cycling algorithm was adjusted from the chamber's interface. Then the test was started. There was no damage to the product during and after the test. The product has been subjected to the maximum and minimum test limits. There are maximum and minimum operating limits specified by the manufacturer for the E-bike battery. In cases where testing requirements exceeded these manufacturer's limits, BMS worked and protected the system. All functions of the product continued to work as designed during and after the test.

5.3.6 Crush test

This test simulates endurance to a crushing force that can be applied to the product. This case may occur during transportation or an accident. Therefore, a test setup was planned that applies a compelling force to the product from the external. A crusher is made according to the dimensions and structure specified in the standard. The product is crushed at a particular speed up to the specified limits with this part. This crush is applied from different angles. After this process is applied to the product, it is checked whether its functions continue normally. Conditions such as overheating, explosion, fire, and rupture should not occur. Also, this equipment has an interface that instantly monitors the force values applied to the product. There is software that can detect the standard requirements in this way and stop the test when necessary. When the product reaches certain crushing values, it can simulate the crush situation by waiting at the point where the test is required. Venting and explosion were not observed in the crush test results applied to the e-bike battery. E-bike battery crush test result was evaluated as "Pass".

A crush test setup, as shown in Figure 31, can be designed such that two metal plates are placed horizontally with a space in between. The battery is seated on the

lower metal plate, and the upper plate is moved downwards at a constant speed.



Figure 31: Crush 50604 Test Setup

5.3.7 Water immersion

This test simulates the situation of a bicycle with an E-bike battery being dropped into or exposed to water. For example; In case of an accident with a bicycle with an E-bike battery, the vehicle may fall into the water. Therefore, it is important to assess this risk. A charged battery is immersed in water containing chemical solution for a certain period of time. The water depth should be at a level that can completely immerse the product in water. In this test, there is a risk of short-circuiting as the product will be completely submerged in water. By adding salt to the water, the conductivity of the water is increased and in this way, the short circuit condition is observed. Since there is a risk of explosion and fire during the test, a remotely controlled system was installed for this test. Submersion status can be controlled with the remote control. The product is placed on a sliding shelf and can be immersed in water by remote intervention. In this way, the product stays in the specially solution containing of water for a certain period of time. All risks are evaluated. As a result of the test, fire and explosion etc. situations should not exist.

The water immersion test was performed to the E-bike battery in the water immersion setup indicated in the figure 32. Test results are no fire, no explosion , no voltage drop , no water inside the housing , battery normally operational after the test



Figure 32: Water Immersion Test Setup

5.3.8 Over-temperature condition test

It tests the safety of the product in case of extreme temperature. If the product has a BMS system, it also controls the protection functionality of the BMS in case of overheating. In the test, the product is placed into the temperature chamber. The chamber temperature is set slightly above the product's maximum performance temperature and an over temperature condition is simulated. This temperature increase level is specified in the standard. The product is kept at a certain level at this extreme temperature limit. In addition, a discharge and charge cycle is applied to the product. There should be no leakage, fire, explosion or rupture in the product.

E-bike batteries were placed in the exproof temperature chamber for over temperature testing. Afterwards, the product was adjusted to the extreme temperature limits specified by the standard. In this state, Thermal stabilization was controlled

by connecting a thermocouple to the product. Also, performed the discharge and charge cycle of the product. During and after the test, no leakage, fire explosion or rupture was observed in the product. E-bike battery resulted as "Pass" in for over temperature.

5.3.9 Under-temperature condition test

Observing the risks that may occur when the product is exposed to low temperatures is the most important purpose of this test. In addition, if the product has a BMS system, the product protection functionality of the BMS is checked at low temperatures (below the limit value). The product is discharged according to the standard and manufacturer's information before testing. Then it is placed in the climatic chamber. The chamber is adjusted to a lower temperature than the minimum temperature limit declared by the manufacturer. The test is started. In addition, charging process is performed to the product. As a result, the product should not charge under this test condition. If there is any charging current, the test will fail. In addition, the product must not be fire or venting.

In the under temperature test, the E-bike battery was first discharged according to the standard and supplier specification information. Then it was placed in the chamber. Low temperature is set from the exproof chamber interface. In this low temperature condition, the product was tried to be charged. However, charging could not be performed. In addition, venting and fire were not detected in the product.

5.3.10 Short circuit

The purpose of the short circuit test is the functionality of the protection structure against the overcurrent that may occur in the product. External short circuits that may occur in the product can cause many serious problems. Therefore, the product must be protected from overcurrent. If the product has a BMS system, it detects overcurrent and puts the product into protection mode in case of short circuit. In

this way, it prevents any risk in the product. The outer casing of the battery should not be observed excess temperature during or after the test. There should be no fire and disassembly.

In the short circuit test of the E-bike battery EN50604, the product is placed in the exproof short circuit chamber. Then it is connected to the short circuit system inside the chamber. This system includes a low ohm resistor specified by the standard. A thermocouple is connected to the product in order to monitor the outer case temperature. When the product is in the chamber, it is short-circuited from the interface. As a result of the short circuit, the BMS structure in the product protected the system. No outer case heating, fire or disassembly occurred. The test result was evaluated as "Pass". The BMS has fulfilled its protection function.

5.3.11 Overcharge protection

The overcharge protection test is to check the function of the overcharge protection function. Thanks to this test, it can be observed what risks arise in case of overcharging in the product and it is controlled whether the overcharge protection prevents this risk. This test check is applied for battery systems. The product is overcharged according to the voltage and current values specified in the standard. In addition, this overcharge condition is applied until the conditions specified by the standard. At the end of the test, fire and disassembly should not occur in the product.

Overcharge protection test was performed to the e-bike battery. The product is connected to the charge-discharge setup. It was applied to the product with a maximum charge of 5A and 42V. The BMS structure has protected the system. Battery has incorporated overcurrent and overvoltage protection. Client also provided safety test report for used battery charger (This indicates that the battery charger equipment that will charge the battery in the field is safe. With this information, the product will be protected from overcharging in 2 ways). As a result, fire and

disassembly did not occur in the product. The test result was evaluated as "Pass".

5.4 BMS Test Results

BMS board controls many important functions in the product. However, one of its most important features is safety protections. There are many BMS safety precautions to protect the risks that may occur in the product. In this way, the product goes to the field as safer. In addition, it prevents the risks that may arise. Therefore the functionality of the BMS is so important. In the general logic of safety tests, the risks of short circuit or open circuit of the components while working in the field are evaluated. When a component is short-circuited or open-circuited, many situations such as malfunctions, explosion, flame, etc. may occur in the product. These situations may interfere with the functionality of the BMS. Risks may arise in the field if this BMS protecting the battery system loses its functionality. For this reason, short-circuit and open-circuit states of the components on the BMS board are simulated. After the test, it is checked whether there are situations such as fire, explosion, overheating. Many side effects can occur in these short-circuit and open-circuit situations. In case of short circuit, overloads of the components may occur and therefore fires may occur. This critical evaluation process is important in safety tests. These short circuit and open short risks that many critical components may encounter in the field are evaluated. In this way, it is aimed to release a safe system to the field. These short and open states; It may occur due to overcurrent, component material strength, out-of-spec current voltage loads, etc. When these problems are occurred A loss of function occurs in the component and the component cannot perform its task. In this case, risks may arise in the system. For this reason, the risks that may be encountered in case of short and short circuit of the products in the field are evaluated. Critical components in particular should be tested. Open-short circuit analyzes of the BMS in the batteries for which safety approval tests were carried out

were made. During the test, the BMS card was evaluated in the most loaded case. In other words, it is in the worst condition that can be used in the field.

The following tables 19 & 20 contain the open-short circuit test results of the BMS board for the E-bike battery used in the tests. The BMS circuit diagram was analyzed and the points that could pose a risk were short-circuited or open-circuited. The test setup was set up to be the worst condition. The product has been loaded according to the maximum limits specified in the specification. Afterwards, the components that may include risk are short-circuited and open-circuited simulated. If these short and open situations occur, the situations that will arise in the field will be observed. After the component short-open circuit is made, the temperature rise is checked with a thermal camera. The short or open status is maintained until the temperature of the components stabilizes. After the test, a long-term flame condition should not be observed.

Table 19: BMS Card Open-Short Test Result

Component	Fault	Result
C7	Short Circuit	No Hazard,No Fire,No excess temperature
Q1 Drain-Source	Short Circuit	No Hazard,No Fire,No excess temperature
Q1 Drain-Gate	Short Circuit	No Hazard,No Fire,No excess temperature
D1	Short Circuit	No Hazard,No Fire,No excess temperature
C49	Short Circuit	No Hazard,No Fire,No excess temperature
D9	Short Circuit	No Hazard,No Fire,No excess temperature
D3	Short Circuit	No Hazard,No Fire,No excess temperature
C28	Short Circuit	No Hazard,No Fire,No excess temperature
C18	Short Circuit	No Hazard,No Fire,No excess temperature
C19	Short Circuit	No Hazard,No Fire,No excess temperature
D11	Short Circuit	No Hazard,No Fire,No excess temperature
U3 6-8 pins	Short Circuit	No Hazard,No Fire,No excess temperature
U3 6-7 pins	Short Circuit	No Hazard,No Fire,No excess temperature
U3 1-8 pins	Short Circuit	No Hazard,No Fire,No excess temperature
Q2	Short Circuit	No Hazard,No Fire,No excess temperature
D68 pins	Short Circuit	No Hazard,No Fire,No excess temperature
D4	Short Circuit	No Hazard,No Fire,No excess temperature
R2	Open Circuit	No Hazard,No Fire,No excess temperature
D6	Short Circuit	No Hazard,No Fire,No excess temperature
D13	Short Circuit	No Hazard,No Fire,No excess temperature
D15	Short Circuit	No Hazard,No Fire,No excess temperature
D19	Short Circuit	No Hazard,No Fire,No excess temperature
U5 1-9 pins	Short Circuit	No Hazard,No Fire,No excess temperature
U5 2-9 pins	Short Circuit	No Hazard,No Fire,No excess temperature
R193	Open Circuit	No Hazard,No Fire,No excess temperature
Q37 Drain-Source	Short Circuit	No Hazard,No Fire,No excess temperature
Q37 Drain-Gate	Short Circuit	No Hazard,No Fire,No excess temperature
C99	Short Circuit	No Hazard,No Fire,No excess temperature
D66	Short Circuit	No Hazard,No Fire,No excess temperature
D67	Short Circuit	No Hazard,No Fire,No excess temperature
D34	Short Circuit	No Hazard,No Fire,No excess temperature
R87	Open Circuit	No Hazard,No Fire,No excess temperature
D40	Short Circuit	No Hazard,No Fire,No excess temperature
D42	Short Circuit	No Hazard,No Fire,No excess temperature
C101	Short Circuit	No Hazard,No Fire,No excess temperature

Table 20: BMS Card Open-Short Test Result

Component	Fault	Result
R140	Open Circuit	No Hazard,No Fire,No excess temperature
C47	Short Circuit	No Hazard,No Fire,No excess temperature
C51	Short Circuit	No Hazard,No Fire,No excess temperature
D37	Short Circuit	No Hazard,No Fire,No excess temperature
C36	Short Circuit	No Hazard,No Fire,No excess temperature
R60	Short Circuit	No Hazard,No Fire,No excess temperature
C61	Short Circuit	No Hazard,No Fire,No excess temperature
C65	Short Circuit	No Hazard,No Fire,No excess temperature
U10 2-8 pins	Short Circuit	No Hazard,No Fire,No excess temperature
U10 7-8 pins	Short Circuit	No Hazard,No Fire,No excess temperature
U17 1-2 pins	Short Circuit	No Hazard,No Fire,No excess temperature
U17 8-4 pins	Short Circuit	No Hazard,No Fire,No excess temperature
U17 1-4 pins	Short Circuit	No Hazard,No Fire,No excess temperature
U11 3-2 pins	Short Circuit	No Hazard,No Fire,No excess temperature
C63	Short Circuit	No Hazard,No Fire,No excess temperature
C59	Short Circuit	No Hazard,No Fire,No excess temperature
U8 1-4 pins	Short Circuit	No Hazard,No Fire,No excess temperature
U8 2-4 pins	Short Circuit	No Hazard,No Fire,No excess temperature
U8 1-2 pins	Short Circuit	No Hazard,No Fire,No excess temperature
U13 2-3 pins	Short Circuit	No Hazard,No Fire,No excess temperature
U13 3-5 pins	Short Circuit	No Hazard,No Fire,No excess temperature
U13 3-8 pins	Short Circuit	No Hazard,No Fire,No excess temperature
C81	Short Circuit	No Hazard,No Fire,No excess temperature
C82	Short Circuit	No Hazard,No Fire,No excess temperature
C91	Short Circuit	No Hazard,No Fire,No excess temperature
U7 4-8 pins	Short Circuit	No Hazard,No Fire,No excess temperature
U16 3-8 pins	Short Circuit	No Hazard,No Fire,No excess temperature

CHAPTER VI

CONCLUSION

This thesis study aimed to establish the first laboratory in Turkey at Vestel Electronic in accordance with IEC 62133-2, IEC62281 and EN50604 standards, to establish the required test setups and to carried out the tests. There was no laboratory in Turkey that could test and approve batteries and cells in accordance with these standards. Battery manufacturers in Turkey had to send their products abroad for approval. After the laboratory was established, many Turkish battery manufacturers requested test support. Approval processes in Turkey provide benefits in terms of both cost and time. In this study, the studies of an E-bike project are presented. Information about Cell, battery and E-bike batteries is given. Since the e-bike product includes a battery management system, the functions of the BMS system are explained in detail. The general requirements for IEC 62133-2, IEC62281 and EN50604-1, which are the necessary IEC standards for E-bike batteries to be approved, are given. There are environmental, mechanical and electrical test requirements in the standards. The application methods of the tests were examined. Since battery tests are risky, the process of establishing a battery laboratory is quite difficult. In case of fire in batteries, it is very difficult to extinguish. Therefore, security measures should be of the highest level. In this thesis, these installation processes and the safe solutions found were explained. Accreditation and CTF processes taken to the laboratory were explained. Devices and their calibration status, fire resistance status of the devices were explained. While designing the fire safety measures and setups that can be taken for the laboratory, the safety measures applied against the fire were explained in detail. The logic of the setup of all IEC62133-2 , IEC62281 and EN 50604-1 tests

was transferred, and then the test results performed to E-bike batteries were shared. Approval status was evaluated according to the test results. The E-bike project tests applied in the thesis study were successfully completed. In addition, open-short tests of the BMS card in the product were carried out and the risks that may occur in the field were evaluated.



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