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Battery concept for 2- and 3-wheelers

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TITLE

Battery concept for 2- and 3-wheelers

AUTHORS

Juan Carriquiry, UEMI

DISCLAIMER

Review

Marco Mammetti, IDIADA

Oliver Lah, UEMI

PICTURES

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1 Introduction

The global shift towards sustainable and eco-friendly transportation solutions has brought electric mobility to the forefront of the automotive industry. Among the various segments of electric vehicles (EVs), two- and three-wheelers play a pivotal role, especially in urban and peri-urban areas where they serve as a primary mode of transport for millions of people. These vehicles, which include motorcycles, scooters, and auto-rickshaws, are crucial for daily commutes, delivery services, and small-scale commercial activities.

Electric two- and three-wheelers offer significant advantages over their internal combustion engine (ICE) counterparts. Firstly, they produce zero tailpipe emissions, contributing to improved air quality and reduced greenhouse gas emissions in cities. This is particularly important in densely populated urban areas where air pollution is a major public health concern. Secondly, electric vehicles are quieter, which helps in reducing noise pollution, enhancing the quality of life in urban settings.

The importance of electrifying two- and three-wheelers extends beyond environmental benefits. Economically, these vehicles are often more affordable to operate and maintain due to fewer moving parts and lower fuel costs. This affordability is crucial in developing countries where two- and three-wheelers are a primary mode of transportation for low- and middle-income populations. Furthermore, the adoption of electric mobility in this segment can reduce dependence on fossil fuels, enhance energy security, and stimulate the growth of new industries and job opportunities in the clean energy sector.

The context of electric mobility for two- and three-wheelers also encompasses the rapid technological advancements and supportive policy frameworks driving this transition. Governments worldwide are implementing incentives, subsidies, and regulatory measures to promote the adoption of electric vehicles. In parallel, advancements in battery technology and energy management systems are making electric two- and three-wheelers more viable and attractive to consumers.

However, the electrification of two- and three-wheelers presents unique challenges. These vehicles require compact, lightweight, and cost-effective battery solutions that can provide adequate range and performance while maintaining affordability. Additionally, the charging infrastructure needs to be accessible and efficient to support widespread adoption. Addressing these challenges requires innovative approaches and continuous research and development in battery technologies and energy management systems.

In summary, the electrification of two- and three-wheelers is not only a critical component of the global effort to mitigate climate change and reduce urban pollution but also a practical solution for enhancing urban mobility and economic efficiency. The following sections of this paper will delve deeper into the innovative battery technologies and energy management systems that are at the heart of this transformation, exploring their applications and potential to revolutionize the two- and three-wheeler market.

2 Challenges and Opportunities in Electrifying 2&3-wheelers

Electrifying two- and three-wheeler vehicles presents a unique set of challenges and opportunities, driven by the specific requirements and market dynamics of these vehicle segments. Understanding and addressing these challenges while leveraging the opportunities is crucial for the successful adoption of electric mobility in this domain.

2.1 Challenges

- **Battery Size and Weight**: Two- and three-wheelers have limited space and load-bearing capacity, making it challenging to integrate large and heavy battery packs. Finding the right balance between battery size, weight, and vehicle performance is essential to ensure these vehicles remain efficient and practical for everyday use.

- **Range and Performance**: Range anxiety remains a significant concern for potential users of electric two- and three-wheelers. Ensuring that these vehicles can travel sufficient distances on a single charge while maintaining performance comparable to ICE vehicles is crucial for consumer acceptance.

- **Cost and Affordability**: The initial cost of electric two- and three-wheelers is often higher than that of their ICE counterparts, primarily due to the cost of batteries. Making these vehicles affordable without compromising on quality and performance is a key challenge that needs to be addressed to drive widespread adoption.

- **Charging Infrastructure**: The lack of a widespread and accessible charging infrastructure is a major barrier to the adoption of electric vehicles. For two- and three-wheelers, this challenge is compounded by the need for convenient and rapid charging solutions that cater to urban environments and short-distance travel patterns.

- **Battery Life and Recycling**: Ensuring long battery life and developing efficient recycling processes are critical for the sustainability of electric vehicles. The environmental impact of battery production and disposal needs to be minimized to truly realize the benefits of electric mobility.

- **Consumer Awareness and Acceptance**: Many consumers are still unaware of the benefits and capabilities of electric two- and three-wheelers. Overcoming misconceptions and building trust in these new technologies is essential for increasing market penetration.

2.2 Opportunities

- **Technological Advancements**: Rapid advancements in battery technology, such as the development of higher energy density batteries and solid-state batteries, offer significant opportunities to overcome current limitations. These technologies can lead to lighter, more efficient, and longer-lasting battery solutions tailored for two- and three-wheelers.

- **Policy Support and Incentives**: Governments worldwide are recognizing the importance of electric mobility and are implementing supportive policies, incentives, and subsidies to encourage the adoption of electric vehicles. These measures can help reduce the initial cost burden and make electric two- and three-wheelers more attractive to consumers.

- **Urban Mobility Solutions**: Electric two- and three-wheelers are particularly well-suited for urban environments where short commutes and frequent stops are common. They offer a sustainable solution for reducing traffic congestion, lowering emissions, and improving air quality in cities.

- **Innovative Business Models**: New business models, such as battery swapping stations and shared mobility services, present opportunities to address some of the key challenges related to charging infrastructure and range anxiety. These models can enhance the convenience and accessibility of electric two- and three-wheelers.

- **Economic Benefits**: The growth of the electric vehicle market can stimulate economic development by creating new industries and job opportunities in the production, maintenance, and recycling of electric vehicles and batteries. It also reduces dependence on imported fossil fuels, enhancing energy security.

- **Environmental Impact**: The widespread adoption of electric two- and three-wheelers can significantly reduce greenhouse gas emissions and air pollution, contributing to global efforts to combat climate change and improve public health.

In conclusion, while there are significant challenges to the electrification of two- and three-wheelers, the opportunities presented by technological advancements, supportive policies, and innovative business models offer a promising path forward. By addressing these challenges and capitalizing on the opportunities, electric two- and three-wheelers can play a crucial role in the future of sustainable urban mobility.

3 Two-Wheelers and Three-Wheelers Caracterization

3.1 General Description of Two-Wheelers

Two-wheelers refer to vehicles designed to be ridden by one or two persons and are characterized by their two-wheel configuration. They are known for their agility, maneuverability, and efficiency. Two-wheelers encompass two main categories:

Motorcycles: Motorcycles are powered vehicles typically equipped with an internal combustion engine or electric motor. They feature varying engine displacements and are designed for different purposes, including sport, touring, and commuting. Motorcycles often have manual or automatic transmission systems and are favored for their speed, acceleration, and handling capabilities.

Scooters: Scooters are lightweight, two-wheeled vehicles designed for urban commuting and short-distance travel. They are characterized by a step-through chassis design, making them easy to mount and dismount. Scooters are powered by smaller internal combustion engines or electric motors, often with automatic transmission systems. They are popular for their fuel efficiency, compact size, and ease of maneuverability in congested city streets.

3.2 General Description of Three-Wheelers

Three-wheelers, also known as trikes or tricycles, are vehicles equipped with three wheels. They offer enhanced stability compared to two-wheelers and can accommodate more passengers or cargo. Three-wheelers serve various purposes:

Three-wheelers are commonly used as auto rickshaws (tuk-tuks) in many countries for passenger transport. They are also employed as delivery vehicles for goods and services in urban and rural areas. Electric three-wheelers are gaining popularity due to their environmental benefits and operational efficiency.

3.3 Main differences between Two-Wheelers and Three-Wheelers

3.3.1 Stability and Handling

Two-wheelers:

- Motorcycles and scooters rely on gyroscopic effects for stability, especially at higher speeds.
- Typically have a single front fork or telescopic suspension system and a rear swingarm with a single rear wheel.
- Steering is achieved through handlebars, offering agility and responsiveness.

Three-wheelers:

- Prioritize stability over maneuverability, especially at lower speeds and during turns.
- Common configurations include a wider wheelbase with two wheels at the front (delta) or two wheels at the rear (tadpole).
- This setup provides enhanced stability, making them suitable for passenger transport and cargo applications.

3.3.2 Powertrain Configuration

Two-wheelers:

- Compact and lightweight powertrains.
- Typically feature small-displacement internal combustion engines (ICE) or electric motors.
- Transmission system (if applicable) transfers power directly to the rear wheel via chain or belt drive.

Three-wheelers:

- Varied configurations based on design and use case.
- Similar ICE or electric motor setups but may include additional components like differentials or dual front-wheel drivetrains.

3.3.3 Load-Bearing Capacity

Two-wheelers:

- Designed primarily for one or two passengers with limited cargo capacity.

Three-wheelers:

- Can accommodate more passengers or cargo due to additional stability and weight-bearing capacity.
- Commonly used for commercial purposes such as delivery vehicles or taxis.

3.3.4 Regulations and Classification

Two-wheelers:

- Governed by specific regulations related to emission standards, safety requirements, and maneuverability tests.

Three-wheelers:

- Classified differently from motorcycles due to additional wheel(s) and stability features.
- Regulations may vary significantly by region, influencing design and use cases.

3.3.5 Market and Application

Two-wheelers:

- Widely used for personal transportation, commuting, and recreation.

Three-wheelers:

- Commonly employed in commercial applications such as cargo transport, passenger taxis, and specialized vehicles.
- Balance stability, load capacity, and maneuverability for specific operational environments.

4 Vehicle Movement Equations

Understanding the movement of vehicles, particularly electric two- and three-wheelers, requires a grasp of several key concepts from physics and engineering. These concepts are foundational for modeling vehicle dynamics, optimizing performance, and improving efficiency. Here are the main concepts involved in vehicle movement equations:

4.1 Forces Acting on the Vehicle

The movement of a vehicle is governed by the forces acting on it. The primary forces involved in the longitudinal dynamics of the vehicle include [4]:

4.1.1 Tractive Force (F_trac)

The force generated by the vehicle's powertrain (motor and wheels) to propel the vehicle forward. For electric vehicles, this force is provided by the electric motor.

4.1.2 Resistive Forces

- **Aerodynamic Drag (F_drag)**: The resistance encountered due to the air the vehicle moves through. It is proportional to the square of the vehicle's speed and is calculated as:

$$F_{\text{drag}} = \frac{1}{2} \cdot \rho \cdot C_d \cdot A \cdot v^2$$

  where ρ is the air density, C_d is the drag coefficient, A is the frontal area of the vehicle, and v is the vehicle speed.

- **Rolling Resistance (F_roll)**: The resistance due to the deformation of tires and the surface they move on. It is given by:

$$F_{\text{roll}} = C_r \cdot m \cdot g$$

where C_r is the rolling resistance coefficient, m is the vehicle mass, and g is the acceleration due to gravity.

- **Gravitational Force (F grade)**: The component of the vehicle's weight acting along an inclined plane (road grade). For a vehicle moving uphill or downhill, this force is:

$$F_{\text{grade}} = m \cdot g \cdot \sin(\vartheta)$$

where ϑ is the road incline angle.

4.2 Newton's Second Law of Motion

The fundamental equation governing vehicle motion is derived from Newton's Second Law:

$$F_{\text{net}} = m \cdot a$$

where F_{net} is the net force acting on the vehicle, m is the vehicle mass, and a is the acceleration. The net force is the difference between the tractive force and the sum of all resistive forces:

$$F_{\text{net}} = F_{\text{trac}} - (F_{\text{drag}} + F_{\text{roll}} + F_{\text{grade}})$$

4.3 Power and Energy Consumption

Understanding how a vehicle utilizes power and consumes energy is critical for electric vehicles. The power required by the vehicle is:

$$P = F_{\text{trac}} \cdot v$$

where P is the power and v is the vehicle speed.

The energy consumed over a time duration T can be calculated as:

$$\int \mathrm{Pdt}$$

4.4 Efficiency and Losses

In electric vehicles, efficiency and losses are crucial factors. The efficiency (η) of the motor and drivetrain affects how much of the electrical energy is converted into mechanical energy:

$$P_{\text{mechanical}} = \eta \cdot P_{\text{electrical}}$$

Losses include:

- **Electrical losses**: Due to resistance in wires and components.
- **Mechanical losses**: Due to friction in moving parts.
- **Thermal losses**: Heat generated by various components.

4.5 Regenerative Braking

Electric vehicles can recover energy during braking through regenerative braking. The kinetic energy of the vehicle is partially converted back into electrical energy and stored in the battery:

$$E_{\text{regen}} = \eta_{\text{regen}} \cdot \frac{1}{2} m(v^2 - v_0^2)$$

where η_{regen} is the efficiency of the regenerative braking system.

Furthermore regenerative braking is limited by the maximum acceptable deceleration for comfort and vehicle dynamics possible issues.

a. Dynamic Behavior and Stability

Dynamic behavior includes handling, stability, and ride quality, influenced by the distribution of forces and the vehicle's response to steering, acceleration, and braking. Key aspects include:

- **Center of Mass**: Affects the vehicle's stability and handling.
- **Suspension Dynamics**: Influences ride quality and road holding.
- **Tire Dynamics**: Affects traction, braking, and cornering performance.

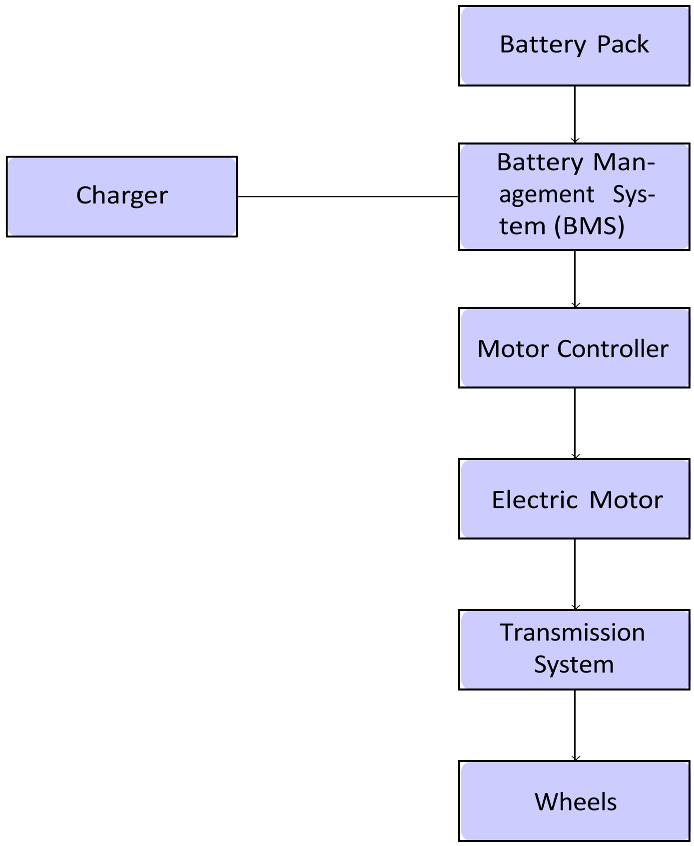
5. Electric 3-Wheeler Powertrain

Three-wheeled vehicles, often known as trikes or 3-wheelers, are a unique category of vehicles that offer a blend of stability and efficiency. These vehicles are particularly popular in urban environments and for short-distance transportation due to their compact size and maneuverability. The powertrain of a 3-wheeler is a crucial component that determines its performance, efficiency, and overall driving experience. This document outlines the main characteristics of 3-wheeler powertrains, highlighting the key components and their functions.

The main components of an electric 3-wheeler powertrain are:

1. **Electric Motor**: Provides propulsion by converting electrical energy into mechanical energy. Commonly used types include BLDC (Brushless DC) motors and PMSM (Permanent Magnet Synchronous Motors).
2. **Battery Pack**: Stores the electrical energy required to power the motor. Lithium-ion batteries are typically used due to their high energy density and efficiency.
3. **Motor Controller**: Regulates the power flow from the battery to the motor, ensuring efficient operation and smooth acceleration and deceleration.
4. **Transmission System**: Transfers the mechanical energy from the motor to the wheels. In many electric 3-wheelers, a simple reduction gear is used instead of a complex transmission system.
5. **Charger**: Charges the battery pack from an external power source.
6. **Battery Management System (BMS)**: Monitors and manages the battery pack, ensuring safe operation and longevity.

a. Block Diagram



In summary, an electric 3-wheeler powertrain consists of several key components that work together to provide efficient and reliable propulsion. The core component is the **electric motor**, which converts electrical energy into mechanical energy to drive the vehicle. Common types include Brushless DC (BLDC) motors and Permanent Magnet Synchronous Motors (PMSM), both known for their high efficiency and reliability. The **battery pack**, typically composed of lithium-ion cells, stores the electrical energy needed by the motor. It is valued for its high energy density, long cycle life, and safety features, which include mechanisms to prevent overcharging and overheating.

The **motor controller** plays a crucial role in regulating the power flow from the battery to the motor, ensuring smooth acceleration and deceleration, and optimizing efficiency. It manages both speed and torque control based on the driver's input and driving conditions. The **transmission system**, often a simple reduction gear, transfers mechanical energy from the motor to the wheels, ensuring efficient power delivery with minimal losses. This simplicity reduces the number of moving parts and lowers maintenance requirements compared to traditional transmission systems.

Supporting these main components are the **charger** and the **Battery Management System (BMS)**. The charger, which can be either on-board or off-board, replenishes the battery pack from an external power source. On-board chargers allow charging from standard electrical outlets, while off-board chargers offer faster charging options. The BMS monitors and manages the battery pack to ensure safe operation and longevity. It performs vital functions such as cell balancing, state of charge estimation, and protection against overcharging, over-discharging, and overheating. Together, these components form an integrated system that provides a reliable and efficient powertrain for electric 3-wheelers.

b. Comparision between Two and Three-Wheelers Powertrain

i. Two-Wheeler Powertrains

1. Two-wheelers, such as motorcycles and scooters, typically feature:
2. Compact and lightweight powertrains designed for agility and maneuver- ability.
3. Small-displacement internal combustion engines (ICE) or electric motors.
4. Transmission systems (if applicable) transferring power directly to the rear wheel via chain or belt drive.
5. Emphasis on responsiveness and efficiency suitable for personal trans- portation.

ii. Three-Wheeler Powertrains

1. Three-wheelers, like trikes and tuk-tuks, differ in powertrain configuration:
2. Varied setups depending on design and application, including:
3. Similar ICE or electric motor setups as two-wheelers but often with additional components:
4. Examples include differentials for rear-wheel drive models or dual front- wheel drivetrains for stability and load-bearing capacity.
5. Used in commercial settings such as cargo transport and passenger taxis, balancing stability and capacity over agility.

6. Overview of Battery Technologies

The rapid evolution of battery technologies has been a cornerstone of the advancement in electric vehicles (EVs), particularly in the burgeoning market of two- and three-wheelers. These compact vehicles demand battery solutions that are not only efficient and high-performing but also lightweight and cost-effective. This section provides an introduction to the various battery technologies that have been developed and refined over the years, each offering unique advantages and addressing specific challenges. From traditional lead-acid batteries to cutting-edge solid-state technologies, the landscape of battery innovation is vast and dynamic. Understanding these technologies is crucial for optimizing the design and performance of electric two- and three-wheelers, paving the way for broader adoption and sustainable urban mobility.

a. Historical Development of Battery Technologies for Vehicles

The development of battery technologies for vehicles has been a journey of continuous innovation and improvement, driven by the need for better performance, efficiency, and sustainability. This historical progression has paved the way for the advanced battery solutions used in today's electric vehicles, including two- and three-wheelers.

i. Lead-Acid Batteries

Early Beginnings: Lead-acid batteries, invented in 1859 by French physicist Gaston Plant´e, were the first rechargeable batteries and quickly became the standard for automotive applications. Their ability to provide high surge currents made them suitable for starting internal combustion engines (ICE), and they have been used in vehicles for over a century.

Characteristics:

1. **Advantages**: Low cost, high availability, and established recycling processes.
2. **Limitations**: Low energy density, heavy weight, and relatively short cycle life.

ii. Nickel-Cadmium (NiCd) and Nickel-Metal Hydride (NiMH) Batteries

Mid-20th Century Innovations: In the mid-20th century, nickel-cadmium (NiCd) batteries were developed, offering better energy density and durability compared to lead-acid batteries. However, environmental concerns and the toxicity of cadmium led to the development of nickel-metal hydride (NiMH) batteries in the 1980s.

Characteristics:

1. **NiCd Advantages**: Improved energy density and performance in low temperatures.
2. **NiCd Limitations**: Environmental toxicity and memory effect.

3. **NiMH Advantages**: Higher energy density than NiCd, better environmental profile.
4. **NiMH Limitations**: Still relatively heavy and less energy-dense compared to later technologies.

iii. Lithium-Ion Batteries

Revolution in the 1990s: The commercialization of lithium-ion (Li-ion) batteries in the 1990s marked a significant leap forward in battery technology. Developed through collaborative efforts by researchers including John B. Goodenough, M. Stanley Whittingham, and Akira Yoshino, Li-ion batteries offered a superior energy density, lighter weight, and longer cycle life.

Characteristics:

1. **Advantages**: High energy density, long cycle life, and efficiency.
2. **Limitations**: Higher cost, safety concerns (thermal runaway), and resource dependence (lithium and cobalt).

iv. Solid-State Batteries

Next-Generation Technologies: Solid-state batteries represent the forefront of battery innovation, aiming to replace the liquid electrolytes in conventional Li-ion batteries with solid electrolytes. This transition promises to enhance safety, energy density, and longevity.

Characteristics:

1. **Advantages**: Improved safety, higher energy density, and potential for longer cycle life.
2. **Limitations**: Currently in developmental stages with high production costs and material challenges.

v. Emerging and Alternative Technologies

Recent Developments: Recent years have seen the exploration of alternative chemistries such as lithium-sulfur (Li-S) and sodium-ion batteries, driven by the need for more sustainable and cost-effective solutions. These technologies aim to address the limitations of traditional batteries while offering unique benefits.

Characteristics:

1. **Lithium-Sulfur (Li-S)**: High theoretical energy density, lower cost materials, but limited cycle life and stability issues.
2. **Sodium-Ion**: Abundant and inexpensive materials, but lower energy density compared to Li-ion,

making them more suitable for specific applications.

In conclusion, the historical development of battery technologies for vehicles highlights a trajectory of innovation aimed at improving energy density, safety, cost, and environmental impact. Each stage of development has brought us closer to realizing the full potential of electric vehicles, particularly in the context of two- and three-wheelers, where compact, efficient, and affordable battery solutions are essential.

b. Predominantly Used Battery Technology: Lithium-Ion Batteries

Among the various battery technologies developed over the years, lithium-ion (Li-ion) batteries are currently the most widely used for electric vehicles (EVs), including two- and three-wheelers. Their dominance in the market is due to several key factors:

i. Advantages of Lithium-Ion Batteries

1. **High Energy Density**: Lithium-ion batteries offer a superior energy density compared to other battery types, which translates into longer driving ranges and better performance. This makes them highly suit- able for the compact and lightweight design requirements of two- and three-wheelers.

2. **Efficiency**: These batteries have high energy efficiency, meaning they can store and release energy more effectively. This efficiency is crucial for maximizing the range and reducing energy losses during use.

3. **Long Cycle Life**: Lithium-ion batteries have a longer cycle life than lead-acid and nickel-metal hydride (NiMH) batteries, meaning they can be charged and discharged many more times before their capacity signif- icantly degrades. This longevity is important for reducing the total cost of ownership.

4. **Rapid Charging**: Advances in lithium-ion technology have enabled faster charging times, which is essential for the convenience and usability of elec- tric vehicles, especially in urban settings where quick turnaround times are necessary.

5. **Weight and Size**: The relatively lightweight and compact size of lithium- ion batteries make them ideal for two- and three-wheelers, where space and

weight constraints are critical factors.

ii. Common Variants of Lithium-Ion Batteries

1. **Lithium Nickel Manganese Cobalt Oxide (NMC)**: Balances energy density, power, and longevity, commonly used in a variety of EVs.

2. **Lithium Iron Phosphate (LFP)**: Known for its safety and thermal stability, often used in applications where these factors are prioritized over energy density.

3. **Lithium Nickel Cobalt Aluminum Oxide (NCA)**: High energy den- sity and power, frequently used in high-performance vehicles.

iii. **Market Penetration**

Lithium-ion batteries are ubiquitous in the electric vehicle market due to their well-rounded performance characteristics. They are found in:

1. **Electric Scooters and Motorcycles**: Many popular models from com- panies like Tesla, Zero Motorcycles, and Gogoro use lithium-ion batteries for their balance of range and performance.

2. **Electric Auto-Rickshaws/Tuc-Tucs**: Widely used in countries like India, where companies like Mahindra Electric and Bajaj are incorporating lithium-ion batteries into their electric three-wheelers.

3. **Consumer Electronics**: Beyond vehicles, lithium-ion batteries are also extensively used in laptops, smartphones, and other portable electronics, benefiting from economies of scale that drive down costs.

In conclusion, lithium-ion batteries are the predominant choice for modern electric two- and three-wheelers due to their high energy density, efficiency, long cycle life, rapid charging capabilities, and favorable weight and size characteristics. Their widespread adoption is supported by continuous technological advancements and a mature supply chain, making them the backbone of current electric mobility solutions.

c. Battery Management System (BMS) characteristics

The **Battery Management System (BMS)** is a critical component of an electric 3-wheeler powertrain. It is responsible for monitoring and managing the battery pack to ensure safe, efficient, and reliable operation. The BMS performs several essential functions:

- **Cell Balancing**: Ensures all cells in the battery pack are charged and discharged evenly, preventing any single cell from becoming overcharged or over-discharged, which can degrade performance or cause failure.
- **State of Charge (SOC) Estimation**: Provides an accurate estimate of the remaining charge in the battery pack, helping to predict the remaining

driving range and plan recharging schedules effectively.

- **Protection Mechanisms**: Protects the battery pack from extreme conditions such as overcharging, over-discharging, overheating, and short circuits. This involves monitoring the temperature, voltage, and current of the battery pack and taking appropriate actions to prevent damage.

- **Data Logging and Diagnostics**: Records key data about the battery pack's performance and health over time, which is useful for diagnostics, warranty claims, and improving future battery designs.
- **Communication**: Interfaces with other powertrain components, such as the motor controller and charger, to optimize overall vehicle performance and efficiency.

By performing these functions, the BMS plays a pivotal role in extending the battery pack's lifespan, enhancing safety, and ensuring the reliable operation of the electric 3-wheeler. Continuous monitoring and management of the battery's condition by the BMS help maintain optimal performance and prevent potential failures.

7. UN R136 Regulation

a. General Scope of the UN R136 Regulation

The UN R136 regulation, issued by the United Nations Economic Commission for Europe (UNECE), sets forth uniform provisions concerning the approval of vehicles with regard to specific requirements for the electric powertrain. It applies to electric and hybrid-electric vehicles, focusing primarily on ensuring the safety, performance, and reliability of these vehicles. The regulation covers a range of technical aspects, including electrical safety, functional safety, battery safety, and performance testing [5].

b. Vehicle Categories Included

The UN R136 regulation specifically applies to the following categories of vehicles, primarily focusing on motorcycles and mopeds:

- **Category L1**: Motorcycles with two wheels, with an engine capacity not exceeding 50 cm* if a thermic engine or with a maximum design speed not exceeding 50 km/h.
- **Category L2**: Motorcycles with three wheels, with an engine capacity not exceeding 50 cm* if a thermic engine or with a maximum design speed not exceeding 50 km/h.
- **Category L3**: Motorcycles with two wheels, with an engine capacity exceeding 50 cm* if a thermic engine and/or with a maximum design speed exceeding 50 km/h.
- **Category L4**: Motorcycles with a sidecar, with an engine capacity exceeding 50 cm* if a thermic engine and/or with a maximum design speed exceeding 50 km/h.

- **Category L5**: Motorcycles with three wheels, with an engine capacity exceeding 50 cm* if a thermic engine and/or with a maximum design speed exceeding 50 km/h.
- **Category L6**: Light quadricycles, with an unladen mass not more than 350 kg, not including the mass of batteries in the case of electric vehicles, and a maximum design speed not exceeding 45 km/h.
- **Category L7**: Heavy quadricycles, with an unladen mass not more than 400 kg (550 kg for vehicles intended for carrying goods), not including the mass of batteries in the case of electric vehicles, and a maximum design speed exceeding 45 km/h.

c. Summary of Main Technical Aspects

The main technical aspects of the UN R136 regulation include:

- **Electrical Safety**: Requirements for protection against electric shock, isolation resistance, and protection against direct contact with live parts. This ensures that the electric powertrain is safe for users and technicians.
- **Functional Safety**: Provisions to ensure that the vehicle's control systems function correctly and safely. This includes requirements for fail-safe operation, diagnostics, and response to failures.
- **Battery Safety**: Specific requirements for the safety of rechargeable energy storage systems (RESS), such as lithium-ion batteries. This covers aspects such as thermal runaway prevention, mechanical integrity, and safety during charging and discharging.
- **Performance Testing**: Defines specific tests and criteria to evaluate the performance and safety of electric powertrains, including testing for electromagnetic compatibility (EMC), endurance, and environmental conditions.
- **Marking and Information**: Requirements for appropriate marking of vehicles and components, and the provision of necessary information and documentation to ensure compliance and safe operation.

8. Communication Requirements for BMS in UN R136

According to the UN R136 regulation, there are no explicit mandates requiring a specific type of communication protocol with the Battery Management System (BMS). The regulation focuses on ensuring the safety, reliability, and performance of the electric powertrain, including the BMS, but it allows flexibility in how these systems achieve compliance with the specified requirements.

a. Communication with BMS

- The BMS can operate in an **autonomous** manner, managing the battery pack's safety and performance independently, without the need for specific communication protocols with other vehicle systems.
- Alternatively, the BMS can be designed to communicate with other components of the electric powertrain, such as the motor controller and charger, to optimize overall vehicle performance and efficiency. This communication can be implemented using various industry-standard protocols or custom solutions, depending on the manufacturer's design and integration requirements.

b. Flexibility in Implementation

The flexibility allowed by UN R136 in the implementation of BMS communication ensures that manufacturers can choose the most suitable approach for their specific vehicle designs. The primary goal is to meet the regulation's safety and performance criteria, whether the BMS operates autonomously or in conjunction with other vehicle systems.

9. Key elements on Euro 7 Draft Standard

The Euro 7 draft standard sets specific requirements for electric and hybrid vehicles, recognizing the growing importance of these vehicle types in the transition to cleaner transportation. The standard aims to address not only the direct emissions from these vehicles but also other sources of pollution associated with their operation [3]. Key aspects include:

a. Limits on Pollutants from Brake and Tire Wear

Electric and hybrid vehicles, while having lower tailpipe emissions, can still contribute to air pollution through brake and tire wear. The Euro 7 standard addresses these non-exhaust emissions by:

- **Brake Wear Particles**: Setting limits on the particulate matter (PM) generated from the braking systems of electric and hybrid vehicles. This involves using advanced brake materials and technologies, such as regenerative braking, to reduce particle emissions.
- **Tire Wear Particles**: Implementing limits on the particles generated from tire wear. This includes promoting the use of durable tire materials and designs that minimize particle release during driving.

b. Requirements for Batteries and Electric Motors

The Euro 7 standard includes specific requirements to ensure that the performance of batteries and electric motors in electric and hybrid vehicles meets high standards for efficiency and durability. Key areas of focus are:

- **Battery Performance and Durability**: Establishing standards for the performance and longevity of batteries used in electric and hybrid vehicles. This includes criteria for energy density, charging efficiency, thermal management, and cycle life to ensure that batteries remain efficient and reliable over the vehicle's lifetime.
- **Electric Motor Efficiency**: Setting performance standards for electric motors to ensure high efficiency and reliability. This includes requirements for energy conversion efficiency, power output, and thermal management to optimize the performance of electric drivetrains.
- **Battery Recycling and Disposal**: Introducing requirements for the recycling and disposal of batteries to minimize environmental impact. This involves promoting the use of recyclable materials and establishing guidelines for safe and efficient battery disposal and recycling processes.

c. Enhanced Monitoring and Reporting

The Euro 7 standard also emphasizes the importance of monitoring and reporting to ensure compliance with these requirements:

- **On-Board Diagnostics (OBD) Systems**: Enhancing OBD systems to monitor the performance of batteries and electric motors continuously. This includes detecting faults and ensuring that the vehicle operates within the defined emission and performance limits.
- **Data Reporting and Transparency**: Requiring manufacturers to provide detailed reports on the performance and durability of batteries and electric motors. This data helps regulatory bodies monitor compliance and encourages continuous improvement in vehicle technology.

By addressing these aspects, the Euro 7 draft standard aims to ensure that electric and hybrid vehicles contribute to a cleaner and more sustainable transportation system, while maintaining high standards of performance and reliability.

10. Inclusion of L-Categorized Vehicles in Euro 7 Draft Standard

a. General Scope

The Euro 7 draft standard primarily aims to further reduce emissions from light-duty and heavy-duty vehicles. While it is comprehensive in addressing passenger cars and commercial vehicles, the specific inclusion of L-category vehicles—such as mopeds, motorcycles, tricycles, and quadricycles ([7]), within the Euro 7 framework has certain considerations:

b. Applicability to L-Categorized Vehicles

- **Emission Limits**: The Euro 7 standard focuses on setting stringent emission limits for pollutants such as nitrogen oxides (NOx), particulate matter (PM), carbon monoxide (CO), and hydrocarbons (HC). While these limits are primarily aimed at passenger and commercial vehicles, L-category vehicles are also subject to similar environmental goals under different regulatory frameworks.
- **Monitoring and Reporting**: L-category vehicles are expected to adopt enhanced on-board diagnostics (OBD) systems and real-driving emissions (RDE) testing to ensure compliance with emission standards. These measures help monitor the vehicle's emission performance in real-world conditions.
- **Technological Adaptation**: Manufacturers of L-category vehicles may need to implement advanced emission control technologies, such as improved catalytic converters and particulate filters, to meet the stringent limits imposed by the Euro 7 standard.

c. Specific Requirements for Electric and Hybrid L-Categorized Vehicles

Electric and hybrid L-category vehicles are increasingly significant in the transition to sustainable transportation. The Euro 7 standard addresses several key aspects for these vehicles:

- **Brake and Tire Wear Emissions**: Similar to larger vehicles, electric and hybrid L-category vehicles must adhere to limits on non-exhaust emissions from brake and tire wear. This involves using regenerative braking systems and durable tire materials to minimize particle emissions.
- **Battery and Motor Performance**: The standard sets performance and durability requirements for batteries and electric motors used in L-category vehicles. This includes criteria for energy efficiency, thermal management, and long-term reliability to ensure optimal performance.
- **Recycling and Disposal**: Provisions for the recycling and safe disposal of batteries are emphasized, encouraging the use of recyclable materials and establishing guidelines for efficient battery disposal processes.
- **On-Board Diagnostics (OBD)**: Enhanced OBD systems are required to continuously monitor the performance of batteries and electric motors, ensuring that these vehicles operate within defined emission and performance limits.

d. Summary

While the Euro 7 draft standard primarily targets light-duty and heavy-duty vehicles, the principles and goals extend to L-category vehicles as well. By adopting stringent emission limits, advanced monitoring systems, and performance standards for electric and hybrid models, the Euro 7 standard aims to create a cleaner and more sustainable transportation system across all vehicle categories.

11. Specific Driving Cycles for Two-Wheelers and Three-Wheelers

a. Two-Wheeler Driving Cycles

1. **World Motorcycle Test Cycle (WMTC)**:
    - Used globally to evaluate fuel consumption and emissions of motorcycles and scooters.
    - Includes urban, rural, and highway segments to simulate varied riding conditions.
2. **Indian Driving Cycle (IDC)**:
    - Specifically designed for motorcycles and scooters in India.
    - Represents typical traffic conditions with different speed and acceleration profiles.

b. Three-Wheeler Driving Cycles

1. **European Driving Cycle (EDC) for L-category vehicles**:
    - Includes three-wheelers and quadricycles.
    - Consists of urban, extra-urban, and combined driving cycles for emissions and fuel consumption testing.
2. **India Specific Test Cycles (ISTC)**:
    - Designed for various vehicle categories including three-wheelers.
    - Provides specific profiles for urban and highway driving conditions prevalent in India.

12. Innovative battery technologies, energy management systems, and their applications in two- and three-wheelers.

a. Introduction

A battery module is composed of multiple single cells connected in series. The number of cells determines the module's voltage range. To increase the capacity, either multiple modules or individual cells can be connected in parallel, depending on the application. The complete battery system includes the connected battery cells and any additional components such as the cell supervision circuit (CSC), battery management system (BMS), thermal management, and contactors [8]. The design of the battery system takes into account the specific characteristics of the battery cells used to ensure their reliability, safety, efficiency, and optimal performance throughout their lifespan. There are two main architectures for designing battery modules: block and modular arrangements.

i. Modular arrangement

Individual modules, each consisting of an appropriate number of single cells, are interconnected to form the battery. Each module includes specific peripherals such as the CSC, contactors, and cooling interfaces. This modular design simplifies the assembly process, particularly when dealing with lower module voltages. It also makes recycling and maintenance easier, as smaller modules can be exchanged more readily. Additionally, the separate module housings reduce the risk of thermal propagation between modules. The arrangement of the modules varies depending on the battery's shape and their placement within the vehicle. In this example, the battery is situated between the front and rear axles. Generally, large battery systems favor a modular architecture for its flexibility and ease of handling lower module voltages.

ii. Block arrangement

The battery system can be designed using either a modular or block architecture. In both designs, all battery cells and peripheral components are housed within a single battery enclosure. This approach minimizes space requirements since the cells are directly connected without separation. However, it also increases the complexity of assembly and disassembly processes due to the high battery voltages. Additionally, this design can raise the risk of thermal runaway propagation from one cell to adjacent cells.

iii. Series and parallel cells connection

Automotive applications require high voltages to reduce the ohmic loss of the power lines. Most pure electric vehicles use battery voltages of about 400 V. In future batteries, voltages are expected to increase to about 800 V. Higher voltages result in lower ohmic losses but also impose greater demands on the system due to high voltage engineering considerations. Battery modules with high voltages and capacities consist of numerous single cells that can be interconnected in various ways.

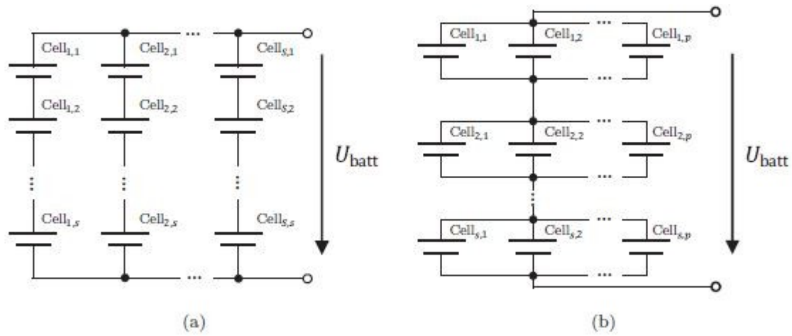


Figure 1: Different possible cell circuitries can be used to enhance the battery voltage U_{batt} and capacitance. Figure (a) shows the parallel connection of serial-connected cells (strings) and Figure (b) shows the serial connection of parallel-connected cells. For equal cell voltages, the battery voltage U_{batt} for both configurations (a) and (b) is the same. In configuration (a), all cell voltages need to be monitored individually. In contrast, the parallel-connected battery cells in configuration (b) balance themselves, requiring only one voltage to be monitored for the parallel connection.

Figure 1 (a) illustrates the parallel connection of strings. Each string comprises cells connected in series. The CSC monitors each cell in the strings to ensure optimal operating conditions. However, this configuration involves significant wiring effort and added complexity. Additionally, it lacks redundancy; if any cell fails, the entire string becomes inoperable. On the other hand, figure 1 (b) shows the serial connection of parallel-connected cells, which enhances redundancy and reduces the wiring effort. Due to the self-balancing nature of parallel-connected cells, the CSC only needs to monitor one voltage per serial-connected module (parallel-connected cells). If one cell is disconnected, the string remains operable.

iv. Battery cells assembly methods

The solid casing of prismatic battery cells offers an optimal geometry for packing without any cavities. The electrodes are designed either as an elliptic coil or a stack. The prismatic shape provides a high surface-to-volume ratio, which ensures good thermal properties. Prismatic pouch cells exhibit even better thermal performance due to their flexible thin aluminum casing and large area tabs. Efficient cooling is achieved by directing heat through the tabs, although the voltage difference between the battery tabs must be managed to prevent short circuits via the cooling components.

Cylindrical cells, familiar to consumer electronics, are also used in electric vehicles, with the 18650 battery cell (18mm diameter and 65mm height) being the most common type. These cells contain wound electrodes housed in a steel or aluminum cylinder. Their compact design and well-established manufacturing process allow for mass production at low costs. However, the compact design and the low ratio between the cell core (volume) and cell surface result in less efficient cooling. This limitation is significant for high-power or high-energy cells. Figure 2 illustrates two packing options for cylindrical cells in battery modules: the hexagonal lattice and the square lattice. On the battery system level, the cylindrical shape restricts the packing density to a theoretical maximum of around 90% with a hexagonal honeycomb-shaped packing. In practice, factors such as safety distances, cell mounting, and space for cooling units reduce the packing density to approximately 60%.

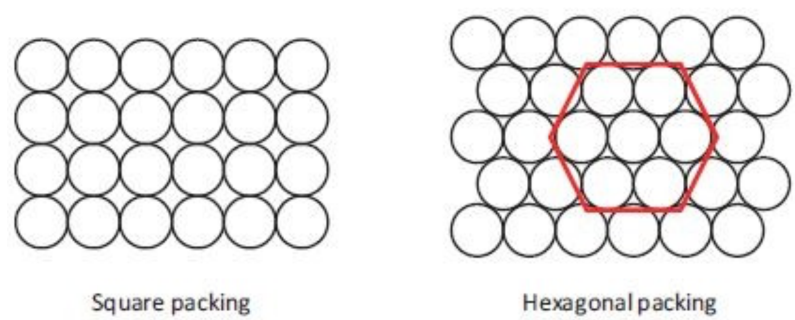


Figure 2: The square and hexagonal packing principles are used for arranging cylindrical battery cells. A hexagonal lattice, where seven cells are arranged in a honeycomb pattern, achieves the highest packing density of 90%. Consequently, the submodule employs this honeycomb geometry.

A design criterion for battery systems is the selection of an appropriate battery cell. Figure 3 shows the three general lithium-ion cell formats. The electrodes can be housed in either a cylindrical or prismatic rigid case, or in a flexible ”pouch bag.” The ”pouch bag” consists of a plastic-coated aluminum foil.

The rigid case of the cylindrical and the prismatic cell resists shocks and static forces and therefore protects the electrodes. In state-of-the-art battery systems, an additional battery housing protects the cells against mechanical shocks and deformation.

The innovative battery architecture approach presented here utilizes rigid cell housing as a structural element of the battery system. By leveraging the area of elastic deformation, this method reduces the weight by minimizing the need for extensive battery housing. The housing is primarily designed to protect the cells from moisture and pollutants. Proper cell arrangement ensures an even distribution of mechanical impacts. Figure 4 illustrates the principle of an integral battery architecture. This concept mirrors the automotive in-

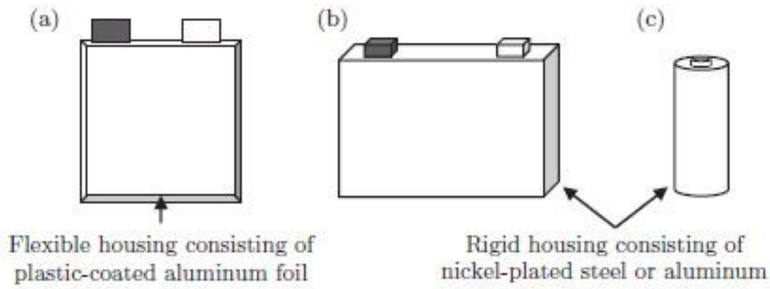


Figure 3: The different types of lithium-ion cells. (a) shows the prismatic geometry with a flexible pouch bag as a housing. (b) presents the prismatic shape and (c) depicts the cylindrical cell type with a rigid housing made of nickel-plated steel or aluminum.

dustry's shift in the 1920s when the unitized body structure was introduced to reduce weight and cost. Before this, passenger cars had a rigid frame or chassis that carried separate bodies and components such as the engine and drivetrain. The unitized body, however, integrated the chassis and bodywork into a single structure, allowing the car itself to bear all loads, resulting in greater rigidity compared to the body-on-frame structure. This methodology is now applied to battery system design.

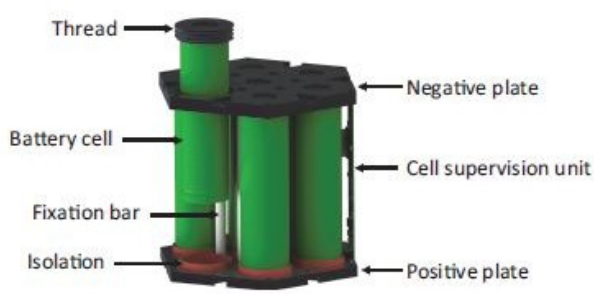


Figure 4: The assembly of the submodule in a modular battery architecture involves integrating individual cells into the structure, as shown in this scheme.

A thread is pressed onto the negative terminal of each battery cell. The cell is then inserted through the negative plate. By tightening the thread into the negative plate, the cell's positive terminal is secured to the positive plate. This process ensures that both the positive and negative plates are connected to the respective terminals of the battery cell electrically, mechanically, and thermally. The fixation bars are used solely to counteract the tensile forces generated during this process.

b. 2&3-wheelers battery pack (module) construction

The following section outlines the boundary conditions and requirements for a battery system with integrated single cells and their implementation in the design process. The primary focus is on using the rigid cell housing as an integral part of the battery system. This approach reduces weight and increases the gravimetric energy density at the system level. Additionally, the design process addresses two key aspects: creating a modular architecture that allows the battery to be used in various applications (such as large sedans, small city cars, scooters, e-bikes, etc.) and developing a simple method for replacing individual battery cells. This simplifies recycling efforts and enhances maintenance efficiency.

Cell connection

The contact resistance between the cell terminals and the cell connectors should ideally be less than one-hundredth of the cell's DC resistance. This guideline ensures that the power loss due to the cell connection is minimal compared to the power loss of the battery cell itself. High contact resistance can result in significant heat generation, which transfers to the battery cell, accelerating degradation and increasing risk. It also reduces efficiency and power capability. Non-separable joints, such as those created by welding, soldering, or gluing, are unsuitable when single cells need to be easily replaceable. Therefore, clamped joints are used to connect the battery cells.

Moisture Proofing

Ensuring the battery is moisture-proof is essential to protect its components, particularly the conductors, from corrosion and wear. Contact corrosion can occur between two connected metals with different electrode potentials in the presence of an electrolyte such as water or moisture. Achieving moisture-proofing requires enclosing the battery within a housing that shields it from moisture and contaminants. This housing does not protect against mechanical impacts. Therefore, materials like composite-layer films, similar to those used in lithium-ion cell pouch bags, or lightweight plastics, can also be utilized.

Lifetime

A lifespan exceeding ten years is a benchmark for passenger cars and is thus also expected for electric vehicle batteries. Achieving this longevity involves complying with automotive standards and passing various tests, including mechanical shock, vibration, and drop tests, as well as electrical and thermal tests. Maintaining a homogeneous temperature distribution within the battery and its cells, in addition to controlling the operating temperature, is crucial for extending the battery's lifespan [2].

Automotive Standards

For a battery pack to be released into the market, it must comply with automotive standards. Table 1 lists the key international standards and regulations for the safety testing of lithium-ion batteries, modules, and cells in automotive applications. These standards cover environmental, electrical, and mechanical abuse tests, which must be considered during the early design stages. Additional standards govern the transportation and storage of battery cells. Moreover, manufacturers' instructions must also be adhered to.

Standard	**Description**
ISO 12405-1	Test specification for lithium-ion traction battery packs and systems, Part 1: High-power applications;
ISO 12405-2	Test specification for lithium-ion traction battery packs and systems, Part 2: High-energy applications
ISO 12405-3	Test specification for lithium-ion traction battery packs and systems, Part 3: Safety performance requirements
IEC 62660-2	Standards for secondary lithium-ion cells for the propulsion of EVs, Part 2: Reliability and abuse testing
IEC 62660-3	Rechargeable cells standards publication secondary lithium-ion cells for the propulsion of electric road vehicles, Part 3: Safety requirements of cells and modules
UN/ECE-R100.02	Uniform provisions concerning the approval of vehicles with regard to specific requirements for the electric power train
UL 2580	Batteries for use in electric vehicles
SAE J2464	Electric and hybrid electric vehicle rechargeable energy storage system safety and abuse testing
SAE J2929	Safety standards for electric and hybrid vehicle propulsion battery systems utilizing lithium-based rechargeable cells
USABC	United States Advanced Battery Consortium — electro-chemical storage system abuse test procedure manual
FreedomCAR	Electrical energy storage systems abuse test manual for EV and HEV applications
KMVSS 18-3	Korea Motor Vehicle Safety Standards for traction batteries
AIS-048	Battery operated vehicles — safety requirements of traction batteries
QC/T 743	Lithium-ion batteries for electric vehicles. Chinese voluntary standards for automobiles

Table 1: Electric vehicle batteries´ main standards selection

No Further Load-Bearing Elements

Minimizing the use of nonstructural components, other than the battery cells themselves, is a key factor in reducing both weight and cost in battery module design. According to [10], a cylindrical 18650 battery cell can endure axial stress of several kilonewtons before failure, maintaining elastic deformation up to about 1.5 kN. This force threshold guides the number of cells in a module to ensure structural integrity and mechanical shock resistance, leveraging the elastic range to prevent cell damage.

Thermal Management

Although natural air convection is the spreadly way to remove heat from battery packs in electric 2&3-wheelers, effective thermal management is essential for extending battery life and performance. Therefore, module designs should facilitate the integration of cooling systems, if that applies. Forced convection can be achieved with airflow between the cells, using either air or liquid. Additionally, cooling plates positioned at the top and bottom of the module help to cool the cells via their terminals. Such types of solutions would be required for high-performance batteries.

Safety Aspects

A cell supervision circuit (CSC) monitors each battery module's voltage and temperature, ensuring optimal operating conditions and preventing critical states such as overcharging and deep discharge. This guarantees that the cells operate within the safe temperature range.

Scalability

For cost efficiency, the module must be adaptable to a wide range of applications and different types of two and three-wheelers. Thus, scalability in terms of electrical variables like capacity and voltage, as well as geometric variables like battery width and height, is crucial. Submodules are interconnected to form larger units through conductive and isolating joints, allowing for both parallel and serial connections. The hexagonal submodule geometry facilitates both horizontal and vertical expansion. Screws through the positive and negative plates reinforce the module and provide additional electrical contacts. This modular design enables the creation of small battery packs for e-bikes or pedelecs, while larger packs for L-categorized 2&3-wheelers can be built by expanding the submodules to fit within the vehicle's chassis.

Exchangeable Single Battery Cells

One key feature of the module is the ability to easily replace individual battery cells, simplifying maintenance, assembly, and recycling. This is achieved through separable joints that ensure simple cell replacement. Cell connectors are clamped onto the cell terminals, with a male thread pressed onto the can to contact the negative pole. The battery cell can be screwed into the negative plate, clamping the positive terminal onto the positive plate. The preload of the screwed cell connects the thread with the negative plate. Additional isolation between the can and the positive terminal ensures that axial forces are absorbed by the can, protecting the positive terminal from deformation. An elastic or adjustable conductor, such as a contact spring, conductive polymer, or grub screw, sets the clamping force and thus the contact resistance.

Gas Channels

In the event of an internal battery cell failure, the generated pressure is released through the cell's pressure vent. For cylindrical 18650 cells, this vent is typically integrated into the positive terminal. The module design incorporates gas channels to direct the flammable gas out of the battery, preventing ignition and further damage. This is achieved through two through-holes in the positive plate for each cell. The pressure vent is allocated at the superior face in prismatic cells.

c. Recent developments for module assembly: Energy Management Systems

The battery management system (BMS) ensures optimal operation of the battery cells. One of its essential functions is monitoring the voltage of each cell in a serial string. Additionally, measuring the temperature, particularly at the hottest point, helps estimate the actual temperature of the cells. Detailed information about the temperature distribution and processes within a complex battery system is crucial for safe and reliable operation. Modern battery systems employ a modular architecture where a set number of cells are monitored by one or a few cell supervision circuits (CSCs). CSCs are physically connected to both the cells and the higher-level BMS via wires. This results in a complex wiring harness, which increases weight, costs, and complexity. Such wiring harnesses also raise the likelihood of failure and limit system modularity. The CSCs and BMS are powered by the battery cells, so their current consumption must be minimal, especially during long idle periods (e.g., when the vehicle is parked), as CSCs can discharge the battery and reduce the vehicle's range. Additionally, unbalanced battery cells in a serial string decrease the usable capacity of the battery. Therefore, modern BMSs offer balancing methods to equalize the cells. This balancing can be passive, where energy is dissipated as heat, or active, where energy is transferred from cells with higher state of charge (SoC) to those with lower SoC.

The innovative approach of the integrated cell supervision circuit (iCSC) involves embedding the modular printed circuit board (PCB) directly into the submodule. The PCB of the iCSC is clamped between the positive and negative plates, forming both the mechanical and electrical interface. This eliminates the need for additional wiring, simplifying the battery assembly process and enabling a highly modular structure. The iCSC monitors the voltage of each cell, measures the temperature at the cell/iCSC interface, and powers itself from the cell voltage. The iCSCs communicate their measured values to a higher-level BMS using an optical communication system. A light-guiding plastic layer on the surface of the battery serves as the common transmission channel, directly connecting the iCSCs with the BMS. This plastic layer acts as the bus medium, with a master-slave organization where the iCSCs are the slaves and the BMS is the master. Additionally, the iCSCs provide a passive balancing method for charge equalization of individual cells and an energy-saving mode that reduces current consumption to 9 μA.

In summary, the key features of the iCSC are:

- The iCSC is powered through the mechanical interface.
- Utilizes cost-effective electronic components.
- Features optical bus communication.
- Ensures galvanic isolation between the iCSCs.
- Employs a modular design.
- Monitors cell voltage from 0V to 4.4V with a 10mV accuracy.
- Measures temperature within the range of 20°C to +80°C.*Hasacurrentconsumptionoflessthan*9 μA in an inactive state.
- Provides passive balancing.

If the state of charge (SoC) of the battery cells in a serial string varies significantly, the iCSC of the cells with the highest SoC will connect a resistor in parallel to the cells. This resistor discharges the cells until the SoC is within the desired operating range, after which the iCSC disconnects the resistor. The passive balancing method can equalize the SoC during charging, discharging, or idle states. Figure 5 illustrates two serially connected submodules with integrated iCSCs and the principle of the balancing circuitry. The PCB dissipates the heat generated by the resistor to the positive and negative plates. Since the cooling system removes heat from the plates, high balancing currents are feasible.

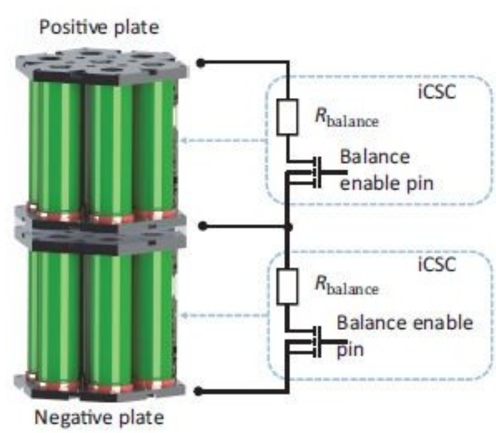


Figure 5: Principle topology of the passive balancing method.

The iCSC's microcontroller can activate a MOSFET through the balance enable pin, connecting a power resistor in parallel to the submodule. This setup discharges the battery cells. The balancing current can be adjusted during the design process by selecting an appropriate resistor value. To ensure adequate thermal conductivity, the resistor's thermal pad is connected to the grounding layer of the PCB.

The PCB of the iCSC is mechanically integrated into the submodule during the assembling process. Initially, the PCB is positioned between the positive and negative plates and then secured by tightening the fixation bars. The gold-plated end caps of the PCB make direct contact with the plates, establishing mechanical, electrical, and thermal interfaces without the need for wiring. Heat dissipated from the electronics is conducted through the end caps to the positive and negative plates, where active cooling could be implemented.

d. Cell connectors and welding technologies

To facilitate a straightforward recycling process for exchangeable single cells, the method of cell connection plays a pivotal role and can be implemented in various ways. This section presents an overview of state-of-the-art joining methods for battery cells and compares their characteristics. A critical aspect in evaluating joint quality is the electrical contact resistance (ECR).

The connection of cylindrical battery cells typically employs methods such as resistance spot welding, ultrasonic welding, laser beam welding, or soldering [6]. Figure 6 illustrates these principal techniques for battery cell interconnection. A significant drawback of these non-separable joints is the complexity involved in disassembly. In contrast, clamped joints facilitate a simple assembly and disassembly process without damaging the joint. Clamped joints are well-suited for high-current applications, including pouch cells, where current tabs are attached to collector bars via brackets. In the submodule, clamped contacts are used to interconnect battery cells with their respective positive or negative plates, ensuring robust connections.

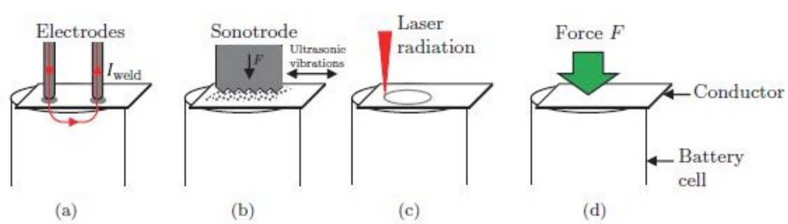


Figure 6: The assembly of the submodule in a modular battery architecture involves integrating individual cells into the structure, as shown in this scheme.

e. Electrical Contact Resistance

The electrical contact resistance (ECR) between the cell connector and the battery terminal is crucial for evaluating joint quality. High ECR or bulk resistance in the cell connector results in heat generation due to ohmic power loss. The high thermal conductivity of cell terminals/tabs transfers this heat into the cell, leading to increased electrode degradation and safety risks. Moreover, high ECR or bulk resistance diminishes the power capability and efficiency of the entire battery system. Soldering, unlike welding processes, does not melt contact elements but joins them through a filler metal (solder). Chemical reactions between contact materials and solder form intermetallic compounds, creating robust bonds with different melting temperatures [9].

Clamped cell connectors

To implement clamped cell connectors for cylindrical 18650 battery cells, achieving a comparable Electrical Contact Resistance (ECR) to welded and soldered cell connectors is essential. Figure 7 illustrates the schematic of the contact interface. Due to the asperities of the contact members, overlaid oxide and contaminant films, only a small portion of the apparent contact area A_a conducts electrical current through the interface, also known as the conducting contact area A_r. The area under load but isolated by a dielectric film is denoted as the load-bearing area A_{lb}. The conducting contact area comprises numerous asperities that restrict current flow, thereby increasing resistance at the interface (constriction resistance). Consequently, the total ECR consists of both constriction resistance and film resistance. Application of force on the contact members deforms the conducting area, increasing contact points and potentially reducing ECR with higher contact forces.

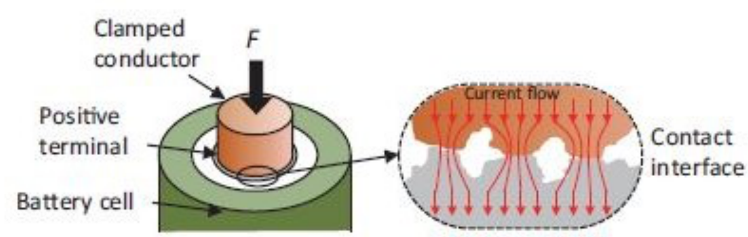


Figure 7: Schematic of the contact interface between the battery terminal and the clamped conductor.

The most significant advantage of a clamped cell connector is its straightforward disassembly process without causing damage. Cell hardness (HB) and specific resistance of the contact elements, along with applied force, are critical parameters for designing clamped contacts. Regarding Electrical Contact Resistance (ECR), materials like Ni, Cu, CuZn, and Al are suitable, considering their standard electrode potential to prevent galvanic corrosion. ECR values for clamped cell connectors fall within or below the range of welded and soldered cell connectors, especially for Cu under $F = 400$ N [1].

f. Conclusions

This chapter has delved into the intricate design considerations and implementation strategies surrounding cylindrical battery cells in the context of electric vehicles, with a particular focus on two- and three-wheelers. Cylindrical cells, exemplified by the ubiquitous 18650 battery, offer significant advantages in terms of mass production and compact design. However, they also present challenges, particularly regarding efficient cooling due to their high core-to-surface area ratio. We explored different packing configurations such as hexagonal and square lattices, illustrating their impact on module density and cooling effectiveness.

The integration of rigid cell housings as structural elements within battery systems marks a significant departure, reminiscent of the unitized body structure in automotive design history. This innovative approach not only reduces overall weight but also enhances mechanical robustness and shields cells from environmental contaminants. We underscored the critical role of modular architectures, which support a wide range of applications from nimble e-bikes to larger vehicles, while facilitating straightforward cell replacement for enhanced maintenance and recycling efficiency.

Central to our discussion were key technical considerations such as minimizing contact resistance and ensuring effective moisture-proofing to optimize battery performance and longevity. We examined cutting-edge energy management systems, including the implementation of integrated cell supervision circuits (iCSCs) and passive balancing techniques, which streamline assembly processes and augment modular flexibility.

Moreover, stringent adherence to automotive standards and safety regulations is paramount for achieving market readiness and instilling consumer confidence. We outlined pivotal international standards governing safety testing, environmental resilience, and transportation protocols for lithium-ion batteries utilized in automotive applications.

Looking ahead, ongoing research and development efforts are crucial to further advancing the efficiency, safety, and sustainability of battery modules for electric vehicles. Future strides in thermal management technologies, scalability solutions, and innovative materials will continue to propel innovation in this dynamic field.

In summary, the integration of cylindrical battery cells into the design of two- and three-wheeler electric vehicles presents a unique blend of challenges and opportunities. By harnessing the potential of modular designs, advanced energy management systems, and rigorous adherence to standards, we can pave the way for a greener and more sustainable future in transportation.

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