BATTERY TESTING STUDY 2016

cigno

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Standards

2 Standards

Battery safety remains one of the main challenges for automotive and battery manufacturers, aside from the development of efficient and reliable battery systems for electric and hybrid vehicles. Hence, government regulators, industry associations, and private research institutions have been grappling for some time with the development of standards to ensure the safe use of such high-voltage components.

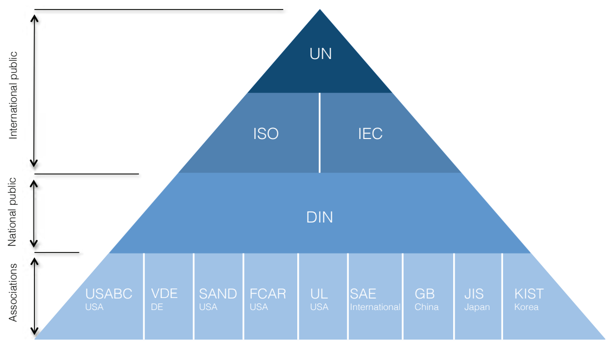


Figure 2.1: Overview of standardization institutes

2.1 Overview of relevant Standards

Due to the international nature of the automotive industry, it is necessary to elevate these norms and standards from the national to the international level. For example, numerous guidelines of the 'International Electro-Technical Commission' (IEC) have already been adopted in Germany by the 'Deutsches Institut für Normung' (DIN). U.S. authorities generally participate actively in the development of new standards and guidelines, too.

The Chinese market has always been difficult for product compliance however. Challenges are caused by a multitude of standards and authorities driving the requirements. Most of these standards are neither adapted to foreign rules and regulations nor available in English. From August 1, 2015, lithium-ion cells and batteries have to pass a series of tests to ensure their safety. The first Chinese mandatory standard is GB 31241-2014.

After successfully passing the tests, the batteries can be sold in the corresponding market. As a result, some unqualified manufacturers and their products will be eliminated. The significance of the reputation of a corporate brand will emerge in the market as consumers will shift their priorities more and more towards high quality and safety. Appendix 6.1 lists existing standards and safety testing organizations.

Ultimately, the successful implementation of standards is dependent on an international and interdisciplinary exchange of all stakeholders. Figure 2.1 shows an overview of important standardization institutions for the battery market.

The energy storage in electric vehicles (hereinafter EV, including battery electric vehicles BEV, hybrid vehicles HEV, plug-in hybrids PHEV and fuel cell vehicles FCV) is mostly lithium-ion battery technology, which is currently still subject to rapidly changing regulatory requirements.
The following section describes the scope of the primary regulatory norms, their implication, commonalities and differences. The following explanation of standards forms the basis for the testing procedures described in chapter 3.

UN/DOT 38.3
This United Nations manual generally applies to the transport of certain dangerous goods. Requirements include testing methods and procedures for the classification of dangerous goods

3
Testing Procedures

3 Testing Procedures

The field of practically applied battery testing procedures has become more complex over the past years. Early standards describe entire test procedures using only a few testing methods. Meanwhile, growing requirements, complex operating systems and increasing experience with battery testing have led to a much wider scope of these testing procedures. Additionally, the documentation of test specifications has become more detailed compared to older standards.

This chapter points out all known test methods and provides a cross standard index containing homogenous notations. The following section gives an extended overview of practically applied testing methods. All procedures can be allocated to one of these three categories:

1. Performance & Life-Cycle Tests
2. Environmental Tests
3. Safety and Abuse Tests

Below, every test method was categorized and described with a few sentences. In case different names were used for the same procedure in varying documentations, multiple terms have been listed to avoid confusion.

3.1 Performance & Life-Cycle Tests

This category of tests is used to determine the performance and durability under different load and usage profiles.

Constant power tests
The objective of this test is to verify a battery's capability of providing energy to the vehicle during a constant discharge. The test is executed throughout a range of predefined power levels.

Testing begins with a pre-conditioning phase of the fully charged battery over one hour. The battery is then discharged with constant power until the minimum voltage, specified by the manufacturer, is reached. One hour later, capacity as well as energy are measured again [33] [34].

Variable power- / drive test
In this test, the actual power consumption of an electric vehicle is simulated using a predefined drive cycle. At the end of the test, capacity as well as energy are measured once more.
To create realistic conditions, random power peaks are required as well as a defined ratio between discharge power and maximum recuperation power.

Energy / Capacity test
The energy test determines the actual capacity of a battery. To do so, a cycle test is initiated in which the battery is first completely charged and then discharged, while measuring the current. Conducting it over different cycles, this test is an essential part of battery maintenance in order to determine the battery's predictable life curve, to locate weak cells and faulty inter-cell connectors. By testing the battery's condition, the reliability and thus longevity of the battery can be optimized [34].

Parameter measurement
Through this test, certain parameters of the battery can be determined, i.e. internal resistance. The parameters are used for the parameterization of the assumed battery models [35].

Energy efficiency test
In this test, the energy used for charging the battery is compared to the usable energy of the battery in order to identify occurring battery power losses [36].

Fast charge test
The aim of this test is to identify the rapid charging capability under high charging rates, and to determine the associated efficiency and effects of fast-charging. The test is performed on the basis of consecutive cycles with increasing charging rates up to twice the normal charge rate [37].

Partial-discharge test
This test is to show how much capacity is lost if the battery is partially discharged several times.

Self-discharge test
Through this test, the self-discharge rate is determined at different charging depths. In order to do so the battery is not used for a defined amount of time [34].

Accelerated aging test
This test involves a series of steps to accelerate battery aging. The processes are derived from everyday use conditions but without massive impairment caused by accidental scenarios. The aim is to stimulate and determine the corresponding failure modes and aging/ degradation mechanisms [38].

Actual use test
The aim of the test is to simulate the conditions of an actual use of the battery in an electric vehicle and to apply it to the battery [34] [39].

End of life prediction test
Based on this test, battery life is estimated. In order to do so the battery is exposed to higher temperatures during cycles of charging and discharging which simulate fast aging.

Calendar lifetime testing
The test is carried out over a longer period of time at different temperatures in order to quantify the reduction of battery capacity. Higher temperatures lead to meaningful results within a shorter period of time. During the end of life prediction test the battery is idle most of the time [40].

Elevated temperature storage test
In this test, the battery is stored for a longer period of time under defined environmental conditions [41].

Reference performance test
This test is used to characterize the degradation of the battery, which appears when the battery is in use. Selected performance tests are carried out during the battery's life cycle at regular intervals [34].

Battery test bench
Source: Voltavision

4

Battery Test Market

4 Battery Test Market

This chapter describes the current situation of the global battery test market: who are the players, what services do they offer, and what is their prognosis for future developments. It also includes company profiles of those who provided more detailed information by answering a questionnaire. Furthermore, table 4.6 in chapter 4.5 at the end of this part gives an international overview of test-portfolio and equipment specifications of 45 additional laboratories. This information was collected from online sources.

Electrical energy storage has become an important topic of discussion for many industries, including applications for automobile (transportation) and stationary grid storages.

An American industry research firm estimated the world demand for primary and secondary (rechargeable) batteries to grow by 7.7 percent per year, amounting to US$120bn in 2019 [55].

Batteries are classified by chemistry. Figure 4.1 illustrates the most common battery classes. Every battery-powered application demands its own specification. Usually, a number of considerations drives the decision including the application's requirements for power and energy, the environment in which the product will be used, and the cost. If the installation space is limited, the size and weight of the battery pack becomes another important argument [56].

Particularly lithium-ion batteries being used for advanced portable and industrial rechargeable batteries (e.g. electric powertrain), experienced significant market growth over the last decade. So far lithium-ion batteries have played their most important role in consumer electronics but in the near future (2016-2025), they are also expected to extensively drive commercial progress within the growing market for electric vehicles and stationary energy storage [57].

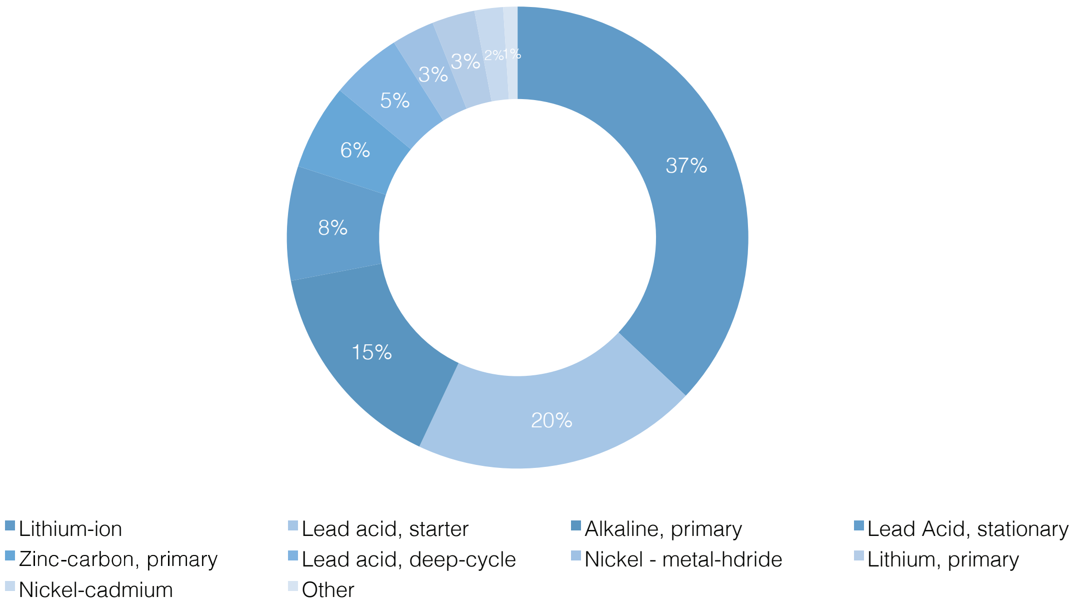


Figure 4.1: Revenue contribution by different battery chemistries [56]

Fast charge	✓	✓	✓
Partial discharge	✓	✓	✓
Self-discharge	✓	✓	✓
Accelerated aging	✓	✓	✓
Actual use	✓	✓	✓
End of life prediction	✓	✓	✓
Calendar lifetime testing	✓	✓	✓
Elevated temperature storage	✓	✓	✓
Reference performance	✓	✓	✓
Baseline life-cycle	✓	✓	✓

Offered Environmental Tests

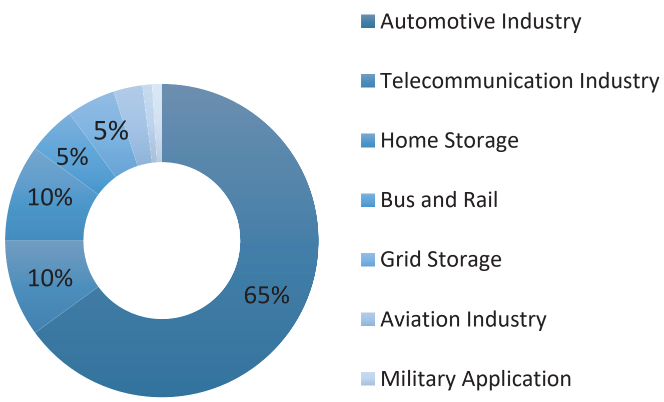
Test	Cell	Module	Pack
Altitude simulation	✓	✓	–
Thermal stability at extreme temperatures	✓	✓	–
Temperature shock	✓	✓	–
Dust	–	–	–
Fog	–	–	–
Chemical exposure	–	–	–
Humidity/salt fog	–	–	–
Immersion	–	–	–
Corrosion	–	–	–
Electromagnetic compatibility and emissions	–	–	–

Offered Safety and Abuse Tests

Test	Cell	Module	Pack
Overcharge	✓	✓	–
Over discharge	✓	✓	✓
Voltage reversal/ forced discharge	✓	✓	–
External short circuit	✓	✓	✓
Internal short circuit	✓	✓	–

Crash	–	–	–
Crush	–	–	–
Shock	✓	✓	–
Drop/ impact	✓	–	–
Vibration	✓	✓	✓
Roll over	–	–	–
Nail penetration	✓	✓	–
Cycling without active cooling	✓	✓	✓
Fire endurance	–	–	–
Gas and particulate analysis	✓	✓	✓

Additional Testing Fields	Fuel cells, Flow Batteries, Primary Batteries, Super Caps
Testable Cell Technologies	Lithium cobalt oxide (LiCoO2) Lithium nickel manganese cobalt (NMC) Lithium manganese oxide (LMO) Lithium iron phosphate(LFP,LiFePO4) Lithium nickel cobalt aluminium oxide (NCA) Lithium titanate (LTO, Li2TiO3) Lithium sulphur (LiS) Lithium air (Li-air) Nickel metal hydride (NiMh) Nickel cadmium (NiCd) Lead-acid (Pb)

Other Areas of Operation	Customer Composition for Battery Testings
Services, battery development, diagnostics	

Performance & life cycle Test Equipment Specifications

	Cell	Module	Pack	Cell	Module	Pack	Cell	Module	Pack	Cell	Module	Pack	Cell	Module	Pack	Cell	Module	Pack
Current range (A) / resolution	A/10A/50A/ 100A/200A /500A/1000 A/2000A	5A/10A/50A /100A/200A /500A/1000 A/2000A	5A/10A/50A /100A/200A /500A/1000 A/2000A	0.005A/1uA, 0.010A/10uA, 5A/100uA, 50A/1mA	50A/1mA, 2000A/ 40mA	50A/1mA, 2000A/40mA	370A / 0.5A	600A / 0.5A	600A / 0,5A	0 - 600A / n.a.	0 - 600A / n.a.	0 - 600A / n.a.	1-4/5/50, 0.002	50/150/300	600/100	0.03uA - 200A/40A	0.1-200 A/0.1A	
Voltage range (V) / resolution	6V / 18V / 60V / 100V 300/ 900V/ 1000V	6V / 18V / 60V / 100V 300/ 900V/ 1000V	6V / 18V / 60V / 100V 300/ 900V/ 1000V	0 - 5 / n.a.	0 - 100 / n.a.	0 - 100 / n.a.	40V / 0.02V	80V / 0.02V	1000V 0.1V ; 600V 0.5V	0 - 800A / n.a.	0 - 800A / n.a.	0 - 800A / n.a.	0/1-5/6, 0.0003	0-6/100	1000/500	5-60V/ 0.003uV	60V/0.06V	
Temperature range (K) / resolution	203 - 453.15 / n.a.	203 - 453.15 / n.a.	203 - 453.15 / n.a.	228 - 453 / 0.3	228 - 453 / 0.3	228 - 453 / 0.3	193 - 473 / n.a.	193 - 473 / n.a.	203 - 373 / n.a.	253.15 - 333.15 / n.a.	253.15 - 333.15 / n.a.	253.15 - 333.15 / n.a.	n.a. / 1	n.a. / 1	n.a. / 1	n.a. / 0.1	n.a. / 0.1	
Number of channels	800	30	10	64	15	15	5	5	2	>5	3	3			2	300	4	
Number of test beds in climatic chamber	800	30	10	2	2	2	1 -10	1 -10	1 - 2	1	1	1				300	4	
Humidity range (%)	-	-	-	0 - 100	0 - 100	0 - 100	<7% - 98%	<7% - 98%	<7% - 98%				0-80%					
Discharge power nominal/maximum (kW)	-	-	up to 240	10.5 / 15	3.6 / 7.2	3.6 / 7.2	4	4 / 100	100	150	150	150	<0.900	7	50/250	0.2	3.6	
Charging power nominal/maximum (kW)				10.5 / 15	3.6 / 7.2	3.6 / 7.2	4	4 / 100	100	150	150	150	<0.900	7	50/250	0.2	3.6	
Temperature change rate (K/min)	10	10	10	5	5	5	10k/min / <10s	10k/min / <10s	10k/min							2.5	2.5	
Determination of thermal capacity (Ws/K)	1	1	1													yes	yes	
Measurable range of internal resistance (Ohm)				from 0.0001	from 0.0001	from 0.0001	0 - 3000 Ohm	0 - 3000 Ohm		mOhm	mOhm	mOhm	0-3 Ohm			0.1 uohm- 260 Ohm	0.6-600 Ohm	
Number of impedance spectroscopes	40	40	40	1	1	1							6			22 Channels, 2 Multiplexer		
Impedance spectroscopy frequency range (Hz) , galvanostatic / potentiostatic	10kHz - 1 mHz	10kHz - 1 mHz	10kHz - 1 mHz	0.000010 - 10000000									10uHz - 4.5kHz			10 uHz - 7 Mhz		
CAN Bus integration	yes	yes	yes	yes			Yes	Yes	Yes	Yes	Yes	Yes			1	yes	yes	
Maximum data sampling frequency (Hz)	1 kHz	1 kHz	1 kHz	1000			1 MHz	1 MHz	1 MHz				100 Hz	10 Hz	10 Hz	1 Mhz	20Hz	
Possibility of flexible/definable load cycles	yes	yes	yes	yes	yes	yes	yes	yes	yes	Yes	Yes	Yes	Yes	Yes	Yes	yes	yes	
Customer access to test data (encrypted remote access / upload to customer server)	no	no	no	yes	yes	yes	yes	yes	yes	Yes	Yes	Yes	yes	yes	yes	no	no	

Figure 4.17: Surveyed companies' performance & life cycle test equipment specifications A

Performance & life cycle Test Equipment Specifications

	Cell	Module	Pack	Cell	Module	Pack	Cell	Module	Pack	Cell	Module	Pack	Cell	Module	Pack	Cell	Module	Pack
Current range (A) / resolution	<250A	<500A	<500A	220 A charging, 740 A discharging	3365 A charging, 365 A dis-charging		15/50/ 100/200						+/-5A - +/-3600A 16 bit	+/-30A - +/-2400A 16 bit	+/-300A - +/-1800A 16 bit	2 - 3000	50 - 800	250 - 600
Voltage range (V) / resolution	0 - 7 V	0 - 60 V	0 - 1000 V	18 V	65 V		0 - 6						-6 - 6V 16 bit	0 - 80V 16 bit	50 - 1000V 16 bit	5 - 20	20 - 100	70 - 1000
Temperature range (K) / resolution	Multiple	Multiple	Multiple	233.15 - 373.5 / n.a.	233.15 - 373.5 / n.a.		233.15 - 373.5 / n.a.						231.15 - 455.15 / n.a.	231.15 - 455.15 / n.a.	228.15 - 413.15 / n.a.	203.15 - 373.15 / n.a.	203.15 - 373.15 / n.a.	203.15 - 373.15 / n.a.
Number of channels	650	100	5	2	1		20						71	57	16	160	55	14
Number of test beds in climatic chamber	all tests in chambers	all tests in chambers	all tests in chambers	1	1		20									2	2	2
Humidity range (%)			0 - 95	no	no								5 - 98% r. F.	5 - 98% r. F.	5 - 98% r. F.	30 - 95	30 - 95	30 - 95
Discharge power nominal/maximum (kW)			750	2	20		1.2						21,6kW	84kW	720kW	9	30	320
Charging power nominal/maximum (kW)			750	3.3	20		1.2						21,6kW	84kW	720kW	9	30	320
Temperature change rate (K/min)	Multiple	Multiple	Multiple		2.0 cooling, 1.0 heating								4K/min	4K/min	3K/min	3	5	3
Determination of thermal capacity (Ws/K)																		
Measurable range of internal resistance (Ohm)																0.03 mOhm - 30 Ohm	0.03 mOhm - 30 Ohm	0.03 mOhm - 30 Ohm
Number of impedance spectroscopes	5						4						35	22	12	10		1
Impedance spectroscopy frequency range (Hz) , galvanostatic / potentiostatic	0.1 - 100000 Hz						mHz to kHz, galvanos-tatic						10mHz - 2kHz (partially up to 5kHz)	10mHz - 2kHz (partially up to 5kHz)	10mHz - 2kHz (partially up to 5kHz)	20 KHz - 1 mHz		20 KHz - 1 mHz
CAN Bus integration	yes	yes	yes				yes						yes	yes	yes		yes	yes
Maximum data sampling frequency (Hz)	< 1 Hz	< 1 Hz	< 1 Hz										20kHz	20kHz	20kHz	100	100	100
Possibility of flexible/definable load cycles	yes	yes	yes				yes						yes	yes	yes	yes	yes	yes
Customer access to test data (encrypted remote access / upload to customer server)	yes	yes	yes				no						yes	yes	yes	upload cloud / server	upload cloud / server	upload cloud / server

Figure 4.18: Surveyed companies' performance & life cycle test equipment specifications B

4.5 Overview of other testing Laboratories

All the information presented in the following tables were collected through publicly available resources and provide an overview on testing services worldwide. Its completeness can not be guaranteed.

Offered test types

		Cell	Module	Pack	Cell	Mod-ule	Pack	Cell	Module	Pack	Cell	Module	Pack	Cell	Module	Pack	Cell	Module	Pack
Performance Tests & Life-Cycle Tests											•	•	•						
	Constant Power																		
	Variable Power/Drive cycle				•	•	•												
	Peak Power																		
	Energy/Capacity Test				•	•	•							•	•	•			
	Parameter measurement	•												•	•	•	•	•	•
	Energy Efficiency																		
	Fast Charge																		
	Partial discharge													•	•	•			
	Self-discharge				•	•	•							•	•	•			
	Accelerated Aging (HALT/HASS)	•	•	•				•	•	•									
	Actual use																		
	End of life prediction																		
	Calender lifetime testing							•	•	•									
	Elevated temperature storage	•	•	•															
	Reference Performance																		
	Baseline Life-Cycle				•	•	•												
Environmental Tests																			
	Altitude Simulation	•	•	•				•	•	•									
	Thermal stability at extreme temperatures	•	•	•	•	•	•	•	•	•				•	•	•	•	•	•
	Temperature shock	•	•	•	•	•	•	•	•	•				•	•	•	•	•	•
	Dust							•	•	•							•	•	•
	Fog							•	•	•									
	Chemical exposure														•				
	Humidity/salt fog	•	•	•													•	•	•
	Immersion				•	•	•	•	•	•									
	Corrosion	•	•	•	•	•	•	•	•	•									
	electromagnetic compatibility & emissions							•	•	•									
Safety & Abuse Tests																			
Electrical	Overcharge	•	•	•															
	Over-discharge	•	•	•	•	•	•												
	Voltage reversal/forced discharge				•	•	•												
	External Short Circuit	•	•	•															
	Internal short circuit																		
Mechanical	Crash	•	•	•															
	Crush																		
	Shock	•	•	•															
	Drop/impact							•	•	•	•	•	•						
	Vibration	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•			
	Roll-over													•	•	•			
	Nail Penetration							•	•	•									
Additional	Cycling without active cooling																		
	Fire endurance																		
	Gas and particulate analysis	•	•	•															

Table 4.6: Services of further laboratories