Reliability Analysis of New Energy Vehicle Batteries

Shishuai Zhao[1]
[1](*School of Mechanical Engineering, University of Shanghai for Science and Technology, China*)

ABSTRACT : *In order to ensure the safe development of New Energy Vehicle(NEV), an in-depth study is conducted on the power batteries to effectively identify the main causes of battery failure and put forward targeted suggestions. Firstly, the main categories of power battery failure are analyzed and a power battery fault tree is established based on the fault tree by combining 16 existing domestic standards. Secondly, based on the hierarchical analysis method, a power battery fault hierarchy analysis model is constructed and the weights of each index are determined by the expert survey method. Finally,the optimization suggestions for the power battery are made according to the calculation results. The article intends to provide theoretical basis and guidance suggestions for the development of power battery reliability design of new energy vehicles.*

KEYWORD –*Cars,batteries,reliability,fault tree*

I.INTRODUCTION

Under the background of low-carbon, informatized, and intelligent development, China's new energy automobile industry has developed rapidly. In October 2020, the "Energy Saving and New Energy Vehicle Technology Roadmap 2.0," led by the China Society of Automotive Engineering, pointed out the direction for future development. However, battery issues remain the primary cause of fire and explosion accidents in new energy vehicles [1], and safety technical problems are becoming increasingly prominent. Accurately evaluating the safety status of power batteries and avoiding safety incidents caused by battery failure is crucial for promoting the safety of new energy vehicles. Nowadays, most fault diagnosis methods rely on hardware redundancy and models. Xia et al. [2] designed a method to obtain fault diagnosis results based on neural networks but did not develop a comprehensive fault diagnosis technology. This paper analyzes the reliability of power batteries based on current domestic standards and proposes optimization measures based on the analysis results [3][4].

II.ACCIDENT ANALYSIS

2.1 Analysis of Typical Accident Types of New Energy Vehicles

With the continuous increase in the number of new energy vehicles, the number of accidents caused by power battery modules has been rising year by year [5]. According to statistics in some literature, the faults are shown in Table 1.

Analysis of typical accident cases shows that battery faults are one of the main causes of fire accidents in new energy vehicles. Therefore, the typical fault types of batteries themselves and their external components are analyzed.

2.1.1Battery malfunction due to its own operation

(1) Overcharge Fault: During the charging process, due to charging faults or abnormal operation of the battery management system, some battery cells may be in an overcharged state. The accumulation of internal chemical reactions leads to losses, and the thermal management of the battery pack becomes out of control, with gas accumulation, eventually leading to an accident.

figure 1 Charging of New Energy Vehicles

(2) Over discharge Fault [6]: When the battery management system is poorly designed, the battery has been in use for too long, or there is an imbalance in current among the battery modules [7],

Serial Number	Time	Location	Vehicle Model	Accident Phenomenon	Accident Cause
1	May-12	Shenzhen	BYD E6	Collision while driving, caught fire	Collision
2	Oct-13	USA	Tesla Model S	Collision while driving, caught fire	Collision, battery fault
3	Nov-13	USA	Tesla Model S	Spontaneous combustion while driving	Battery fault
4	Feb-14	Canada	Tesla Model S	Spontaneous combustion while stationary	Spontaneous
5	Jul-14	USA	Tesla Model S	Hit a roadside pole, caught fire	Collision
6	Apr-15	Shenzhen	Wuzhoulong A10	Sudden fire while charging	Charging fault
7	Nov-15	Shenzhen	BYD E6	Collision while driving, caught fire	Collision
8	Jan-16	Norway	Tesla Model S	Sudden fire while charging	Charging fault
9	Sep-16	Netherlands	Tesla Model S	Hit a roadside tree, sudden fire	Collision
10	Feb-17	Guangzhou	Tesla Model X	Collision while driving, caught fire	Collision
11	Jan-18	Chongqing	Tesla Model S	Spontaneous combustion without charging or collision	Battery fault
12	Aug-18	Guangzhou	Lifan 650EV	Spontaneous combustion while stationary on roadside	Battery water damage fault
13	Mar-19	Shenzhen	BAIC Weiwang 407	Sudden burning while charging	Charging fault
14	Aug-19	Hangzhou	Zotye Cloud 100	Fire while stationary	Battery collision fault

15	Apr-20	Shenzhen	GreenWheel Z3	Sudden spontaneous combustion while charging	Charging fault
16	May-20	Hangzhou	Li Xiang ONE	Sudden spontaneous combustion while stationary	Battery short circuit fault
17	May-21	Jiangsu	Changan Benni EV	Collision while driving, caught fire	Collision
18	Nov-21	Beijing	BYD Qin Pro EV	Sudden spontaneous combustion while charging	Charging fault
19	Mar-22	Shenzhen	Xpeng G3	Sudden spontaneous combustion while stationary	Spontaneous

Table 1 Typical Accidents of New Energy Vehicles from 2012 to 2022

the battery may not stop discharging when it reaches the discharge cut-off voltage, and the self-discharge rate continues to increase, resulting in capacity loss or thermal instability. This affects the battery's tolerance to use.

(3) Internal Short Circuit Fault: Improper manufacturing processes during battery production, such as rough electrode surfaces, can cause the separator to be punctured. Or during use, the battery may be affected by high temperatures, impacts, etc., leading to separator failure and accidental contact between the positive and negative electrodes [8]. Experimental data shows that high-capacity batteries have a higher risk of internal short circuits.

(4) External Short Circuit Fault: When the battery pack is subjected to collisions, water immersion, or leakage, external short circuits may occur. Due to the small external load resistance during an external short circuit [9], the instantaneous current is too large, causing intense heat release from the battery cells. The heat spreads to the surrounding cells, triggering thermal runaway.

(5) Overheating Fault: When overcharging, overdischarging, short circuits, or cooling system malfunctions occur, the battery may experience abnormal temperatures [10], increased impedance, and reduced cycle life. Continuous temperature rise increases the risk of thermal runaway and may even lead to combustion or explosion.

(6) Thermal Runaway Fault: Long-term use and sudden events can cause thermal runaway in battery packs. The main triggers of thermal runaway include mechanical abuse, electrical abuse, and thermal abuse. In a thermal runaway state, continuous secondary reactions occur inside the battery, releasing a large amount of heat and gas, and forming a chain reaction that affects the safety performance of the entire vehicle.

figure 2 Battery combustion caused by vehicle collision

2.1.2 External device failure of the battery

(1) Relying on sensitive sensors, reliable current, voltage and temperature data can be collected. Among them, the failure of current sensors will directly affect the accuracy of SOC and multi-state estimation, while the failure of temperature and voltage sensors will lead to thermal management out of control or balance errors.

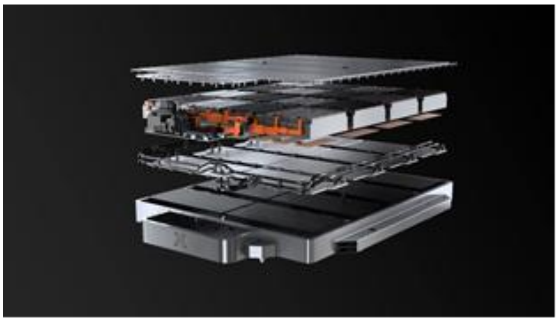

figure 3 Structure of Battery Pack for Automobile Chassis

(2) Battery connection faults: As the vehicle is driven and the external conditions change complexly, the connection between battery terminals may loosen or be corroded, leading to connection faults [11]. When there is a loose connection between batteries, the output power of the battery will be insufficient [12], the resistance will increase and cause Joule heating out of control, which may lead to safety accidents.

(3) Cooling system faults: The power battery dissipates the heat generated by battery reactions through the cooling system. If the cooling system fails, the heat generated inside the battery cannot be dissipated in time, causing the battery to operate outside the normal temperature range [13]. When the temperature of a single battery cell reaches a dangerous critical point, it will trigger a chain of secondary reactions, leading to thermal runaway and then causing combustion and explosion accidents.

2.2 Analysis of Power Battery Faults

2.2.1 Construction of Fault Hierarchical Analysis Model for Power Batteries

Based on the analysis of the causes of faults, taking the faults of power batteries as the target layer, the lower-level faults as the criterion layer, and the detailed causes as the scheme layer, a hierarchical analysis model for the faults of power batteries is constructed [14].

2.2.2Calculation of Weighting Factors for Fault Evaluation Indicators of Power Batteries

Based on the analytic hierarchy process model, the pairwise comparison method is used to construct the judgment matrix, collect the expert scoring results, and conduct matrix construction and quantification processing of the indicators. Through the calculation and analysis of the judgment matrix for battery faults, it is found that the internal short circuit fault has the largest weight, reaching 0.3381, accounting for more than 33% of all faults; the external short circuit fault has the second largest weight, reaching 0.2870, nearly 33%; the overcharge accident has the third largest weight, reaching 0.1346; the sum of the weights of the remaining five faults is 0.2403. Combined with the fault tree analysis of the power battery, it can be known that the three types of faults with the highest weights, namely internal short circuit fault, external short circuit fault, and overcharge fault, belong to thermal runaway faults. Therefore, the key to preventing power battery faults lies in preventing the occurrence of thermal runaway. Through the calculation and analysis of the judgment matrix for internal short circuit faults, it is found that the weight of squeezing is the largest, reaching 0.3163, nearly 33% of all faults; the weight of vibration and impact is the second largest, reaching 0.2247, nearly 25%; the weight of thermal shock is the third largest, reaching 0.1678; the sum of the weights of the remaining six faults is 0.2911. Combined with the fault tree analysis of the power battery, it can be known that the three types of faults with the highest weights, namely squeezing, vibration and impact, and thermal shock, belong to special events. Therefore, the key to preventing internal short circuit faults lies in preventing the occurrence of special events.

Through the calculation and analysis of the external short-circuit fault judgment matrix, it is found that the weight of impact or collision is the largest, reaching 0.6527, accounting for nearly 66% of all faults; the weight of water immersion is the second largest, reaching 0.2851, accounting for nearly 33%; the weight of external short-circuit protection failure is the third largest, reaching 0.0623. Combined with the fault tree analysis of power batteries, it can be known that the key to preventing external short-circuit faults lies in preventing the occurrence of impact accidents. Through the calculation and analysis of the over-discharge fault judgment matrix, it is found that the weight of personnel discharge operation errors is the largest, reaching 0.4988, accounting for nearly 50% of all faults; the weight of overcurrent discharge protection failure is the second largest, reaching 0.2034, accounting for nearly 25%; the weight of discharge current and voltage management failure is the third largest, reaching 0.1266; the weight of low battery power prompt failure is 0.0446. Combined with the fault tree analysis of power batteries, it can be known that the key to preventing over-discharge faults lies in strengthening the charging operation skills of drivers and working technicians. Through the calculation and analysis of the connection fault judgment matrix, it is found that the weight of abnormal personnel operation is the largest, reaching 0.4310, accounting for nearly 50% of all faults; the weight of abnormal charging and swapping equipment and facilities is the second largest, reaching 0.3235, accounting for about 33%; the sum of the weights of the remaining two types of faults is 0.2456. Combined with the fault tree analysis of power batteries, it can be known that the key to preventing connection faults lies in strengthening the connection operation skills of working technicians. Through the calculation and analysis of the cooling system fault judgment matrix, it is found that the weight of mechanical performance abnormalities caused by collisions and other factors is the largest, reaching 0.5436, exceeding 50% of all faults; the weight of abnormal monitoring or alarm systems is the second largest, reaching 0.1846, accounting for about 20%; the sum of the weights of the remaining three types of faults is 0.2719. Combined with the fault tree analysis of power batteries, it can be known that the key to preventing cooling system faults lies in preventing the occurrence of collision accidents.

III. CONCLUSION

From the analysis of the factors influencing the faults of power batteries, machine factors account for 80% of the total; human factors come second. Therefore, to prevent faults in power batteries, it is necessary to try to prevent the machine itself from malfunctioning, avoid special events such as collisions, compressions, and water immersion, and improve the fault protection performance.

REFERENCES.

[1] W.J. Book, Modelling design and control of flexible manipulator arms: A tutorial review, *Proc. 29th IEEE Conf. on Decision and Control*, San Francisco, CA, 1990, 500-506.

[2] Xia, Min, et al. "Fault diagnosis for rotating machinery using multiple sensors and convolutional neural networks." *IEEE/ASME transactions on mechatronics* 23.1 (2017): 101-110.

[3] Bakeer, Abualkasim, et al. "Reliability analysis of battery energy storage system for various stationary applications." *Journal of Energy Storage* 50 (2022): 104217.

[4] Di Trolio, P., et al. "A hybrid power-unit based on a passive fuel cell/battery system for lightweight vehicles." *Applied Energy* 279 (2020): 115734.

[5] Zhang, D. L., et al. "Study on vehicle fire safety: Statistic, investigation methods and experimental analysis." *Safety science* 117 (2019): 194-204.

[6] Xu, Jianing, et al. "A fast diagnosis method for accelerated degradation fault induced by overcharging of LiFePO4 batteries." *Journal of Energy Storage* 46 (2022): 103798.

[7] AswinKarthik, Chandrasekaran, et al. "Thermal management for prevention of failures of lithium ion battery packs in electric vehicles: A review and critical future aspects." *Energy Storage* 2.3 (2020): e137.

[8] Takada, Kazunori, et al. "Positive and negative aspects of interfaces in solid-state batteries." *ACS Energy Letters* 3.1 (2017): 98-103.

[9] Chen, Zeyu, et al. "Electro-thermal coupling model of lithium-ion batteries under external short circuit." *Applied Energy* 293 (2021): 116910

[10] Hou, Junbo, et al. "Fundamentals and challenges of lithium ion batteries at temperatures between− 40 and 60° C." *Advanced Energy Materials* 10.18 (2020): 1904152.

[11] Kaliaperumal, Muthukrishnan, et al. "Cause and mitigation of lithium-ion battery failure—A review." *Materials* 14.19 (2021): 5676.

[12] Wang, Yujie, et al. "Health diagnosis for lithium-ion battery by combining partial incremental capacity and deep belief network during insufficient discharge profile." *IEEE Transactions on Industrial Electronics* 70.11 (2022): 11242-11250.

[13] Ma, Shuai, et al. "Temperature effect and thermal impact in lithium-ion batteries: A review." *Progress in Natural Science: Materials International* 28.6 (2018): 653-666.

[14] Shang, Yuzhao, et al. "Research progress in fault detection of battery systems: a review." *Journal of Energy Storage* 98 (2024): 113079.