Factors Affecting Battery Life of Electric Vehicles

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Abstract: With the progress of the times and the development of science and technology, new energy vehicles have reappeared in front of people, and the development of new energy vehicles is the only way for our country to move from an automobile country to an automobile power, and is a strategic measure to cope with climate change and promote green development. In 2024 New Year's message "new energy vehicles, lithium batteries, and photovoltaic products have added new colors to Made in China." "One of the core components of electric vehicles is the battery, and the battery range is a key factor affecting the adoption of electric vehicles. The improvement of range can not only increase the driving range of electric vehicles and reduce the number of charges, but also improve the driving experience of users and further promote the development of the electric vehicle market. However, the current battery life of electric vehicles still faces many challenges, such as insufficient battery energy density, long charging time, and reduced low-temperature performance, which have become the main bottlenecks restricting the widespread application of electric vehicles. Therefore, it is of great significance to deeply study the influencing factors of electric vehicle battery life and explore effective ways to improve battery life to promote the sustainable and healthy development of our country's new energy vehicle industry.

Keywords: Battery; Electric Vehicle; Lead-Acid Batteries; NiMH Batteries; Lithiumion Batteries; Battery Life

1. Introduction

When delving into the factors affecting EV battery life, we first need to understand the current state of battery technology. At present, lithium-ion batteries are more commonly used in electric vehicle batteries, which are ahead of lead-acid batteries and other batteries due to their long initial battery life and large energy density. However, due to its high cost and large safety hazards, there is still a lot of room for improvement in battery technology.

I divide the factors affecting the battery life of electric vehicles into two categories here. One is the individual product differences caused by the impact of materials and design on electric vehicle batteries in the manufacturing process, and the other is the acquired differences caused by a series of losses caused by external factors such as assembly, application, temperature and acquired use of electric vehicle batteries after leaving the factory.[1-7]

2. Research and Application of Three Types of Electric Vehicle Batteries

The current energy storage technology used in electric vehicles is mainly electrochemical energy storage technology, that is, lead-acid, nickel-metal hydride, nickel-cadmium, lithium-ion, sodium-sulfur and other battery energy storage technologies. Of which lead-acid batteries, cobalt-nickel batteries and lithium-ion batteries are mainly used in the market·[8]

The differences in battery life between lead-acid batteries, cobalt-nickel batteries, and lithium-ion batteries are mainly reflected in material properties, energy storage density, cycle life, temperature adaptability, and safety. The following is analyzed from three dimensions: principle, performance parameters and application scenarios:

2.1 Lead-Acid Battery

Lead-acid batteries are composed of lead cathode, lead anode, and sulfuric acid electrolyte, which store and release electrical energy through the reaction of lead compounds with sulfuric acid. It has a nominal voltage of 2V, a low energy density of only 30-50 Wh/kg, and a short cycle life (300-350 charges and discharges). Its low cost and mature process make it suitable for low-speed electric vehicles (such as electric tricycles) and automotive starter power.

However, the energy density is low (the actual rechargeable capacity is only 35-45 Wh/kg), the cycle life is short (about 300 times), and it is easy to produce heavy metal pollution (lead toxicity). It is mainly used in low-speed electric vehicles, electric forklifts and automobile starting systems, but due to insufficient battery life and pollution problems, its market share is gradually being replaced by lithium-ion batteries. [9-11]

2.2 Cobalt-Nickel Battery (Nickel-Cadmium/Nickel-Metal Hydride Battery)

Nickel-cadmium batteries use nickel oxide as the positive electrode, cadmium as the negative electrode, and electrolyte as alkaline. NiMH batteries use nickel-hydride cathode and lithium alloy anode, and the electrolyte is potassium hydroxide solution. Both are alkaline batteries with a cycle life of more than 1000 times. NiCd batteries have a high energy density (such as NiMH batteries can reach 165 Wh/kg), but attention should be paid to their cycle limit. Warm nickel-cadmium batteries have poor performance at low temperatures (-40°C) and are prone to hydrogen precipitation, leading to the risk of explosion. NiCd batteries produce hydrogen and oxygen during charging and discharging, relying on ventilation systems, while NiMH batteries are relatively safe. In the early days, it was widely used in hybrid vehicles (such as the Toyota Prius), but due to the popularity of lithium-ion batteries, its market share has fallen below 10%. [12]

2.3 Lithium Electronic Battery (Lithium-ion Battery)

Lithium-ion battery uses lithium compounds (such as lithium iron phosphate, ternary cathode) as the positive electrode, graphite as the negative electrode, and electrolyte as organic solvent and lithium salt. The unit voltage is 3.2-4.8V, and the energy density can reach 120-180 Wh/kg. The energy density of lithium iron phosphate batteries is 6-7 times that of lead-acid batteries, and the volume is only 2/318 of that of lead-acid batteries. Lithium-ion batteries can have more than 3000 cycles (lithium iron phosphate) and 6000 times (ternary lithium), and the life is 3-10 times that of lead-acid batteries. It can still maintain a high capacity at -18°C (e.g., 1C discharge can reach 97% of the rated capacity). There is no heavy metal pollution, but overcharging and discharging may lead to thermal runaway, which needs to be managed by the BMS system. It is mainstreamly used in electric vehicles (such as BYD and Tesla), AGVs (such as ternary lithium in port automation) and energy storage equipment (such as lithium iron phosphate in power grid peak shaving). [13-14]

Table1. Comparison of the Characteristics of the Three Batteries

Characteristic	Lead-acid Batteries	Cobalt-nickel Batteries (Nickel-cadmium/NiMH)	Lithium Electronic Battery
Energy Density (Wh/kg)	30-50	165 (NiMH)	120-180
Cycle life (times)	300-350	1,000-3,000 (Nickel hydrogen)	3000-6000
Low temperature performance (-40°C)	Basically normal	Nickel-cadmium needs to be ventilated and explosion-proof	Nickel-metal hydride/lithium iron phosphate can be normal
environmental pollution	Lead toxicity	Nickel-cadmium contamination	No pollution
security	Low (risk of lead leakage)	Medium (Risk of Gas Leaching)	High (BMS management required)

Table 1 is the analysis of the differences between lead-acid batteries, cobalt-nickel batteries and lithium-ion batteries in terms of initial service life and energy density, and also makes specific statements about their practical scenarios. Next, we will analyze the battery life problem from the specific use of the battery.

3. Changes in Battery Life Caused by User Behavior Characteristics

As one of the core components of electric vehicles, the performance difference of the power battery directly affects the performance of the vehicle. However, in the process of power battery recycling, there are often varying degrees of battery aging, resulting in varying degrees of attenuation in battery and vehicle performance.[15]

3.1 Differences in the Location of Users

This paper discusses the effects of different battery operating environment temperatures on battery aging caused by regional differences by comparing and analyzing the differences in vehicle battery aging degree between Beijing and Guangdong. In order to reduce the interference of users' behavior characteristics in the process of discharging and charging on the analysis results, the charging and discharging behavior characteristics of users are controlled, and user vehicles with low-frequency fast charging and aggressive driving style are selected as data analysis samples. The results are shown in Figure 1. The research results show that the battery capacity attenuation of Guangdong vehicles is smaller than that of Beijing vehicles at the same mileage. Specifically, at a mileage of 50,000, 100,000, 150,000 and 200,000 kilometers, the battery aging of user vehicles in Beijing is 19.09%, 10.59%, 16.02% and 11.88% higher than that of user vehicles in Guangdong Province, respectively. Overall, under the same mileage, the battery aging rate of Beijing user vehicles is significantly faster than that of Guangdong user vehicles. This is mainly due to the fact that the operating environment temperature of the battery of Guangdong user vehicles is mainly concentrated between 10~40°C, and the battery works in a normal temperature environment, and the capacity attenuation is small; The temperature in Beijing's spring, autumn and winter is significantly lower than that in Guangdong, especially in winter (<0°C), and the battery cycles aging faster in a low-temperature environment.

3.2 Charging Method Preference

This paper selects vehicle data with aggressive driving style in Guangdong as a sample to analyze the influence of different charging and discharging methods (high-frequency fast charging, medium-frequency fast charging and low-frequency fast charging) on battery aging. The results show that at the same mileage, with the increase of fast charging frequency, the degree of battery aging shows an upward trend. Compared with slow charging, the battery aging of the vehicle of users who prefer fast charging is more significant. The results are shown in Figure 2. Specifically, at a mileage of 50,000, 100,000, 150,000 and 200,000 kilometers, the battery aging of users who prefer high-frequency fast charging increased by 33.45%, 33.86%, 56.24% and 55.02% respectively. In addition, differences are small but statistically significant, and the battery aging of high-frequency fast charging users increased by 3.55%, 3.16%, 7.06% and 0.74% respectively under the same mileage.

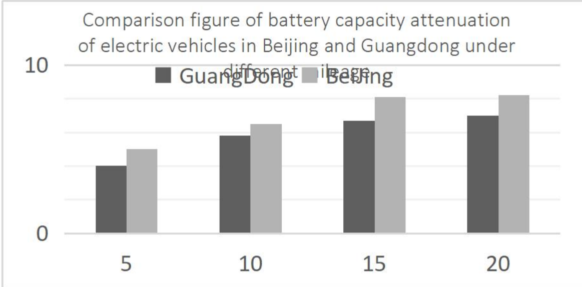

Figure 1. Comparison Figure of Battery Capacity Attenuation of Electric Vehicles in Beijing and Guangdong under Different Mileage

In order to further explore the effect of fast charging frequency on battery capacity attenuation, user vehicles with a mileage of 50,000 kilometers and aggressive driving style in Guangdong were selected as samples to analyze the correspondence between fast charging frequency and battery capacity attenuation. As shown in the figure, with the increase of fast charging frequency, the decay rate of battery capacity gradually increases, but the growth rate gradually decreases. When the fast charging frequency is in the range of 0-0.7, the battery capacity decay rate increases rapidly with the increase of fast charging frequency. When the fast charging frequency exceeds 0.7, the further increase in fast charging frequency has a relatively small impact on the battery capacity decay rate.

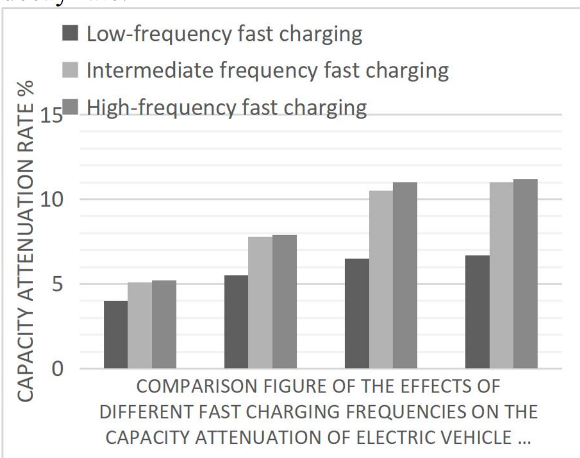

Figure 2. The Influence of Different Charging and Discharging Methods on Battery Aging

It can be seen that there is a significant difference in the impact of fast charging and slow charging on battery aging. This is mainly because the charging current of fast charging is much greater than that of slow charging, and large-rate charging will deviate the battery system from the equilibrium state, accelerate the aging of cathode and anode materials, and may even trigger lithium precipitation reactions, resulting in battery capacity attenuation. At the same time, the heat generated by fast charging will also accelerate battery aging. Therefore, reducing the frequency of fast charging can effectively slow down battery aging, and it is recommended that users give priority to slow charging and replenishment.

3.3 User Driving Style

The user vehicles in the same Guangdong region with low-frequency fast charging were selected as data samples to analyze the influence of different driving styles (aggressive and mild) on battery aging. As can be seen from the figure, at the same mileage, aggressive driving modes have a more significant impact on battery loss than mild driving styles. The results are shown in Figure 1. Specifically, at 50,000, 100,000, 150,000 and 200,000 kilometers, the aging caused by aggressive driving mode increased by 10.37%, 7.53%, 3.14% and 1.73% respectively. This is mainly because aggressive driving styles are often accompanied by high-speed driving and frequent acceleration and deceleration processes, resulting in instantaneous battery discharge and feedback power and average discharge power that are much higher than mild driving styles. During the high-rate discharge process, the polarization phenomenon of the battery is serious, resulting in a significant decrease in the activity of the electrode material, which in turn leads to the decay of the battery capacity. Therefore, users are advised to avoid aggressive driving behavior as much as possible, and choosing a gentle driving style can help extend battery life.

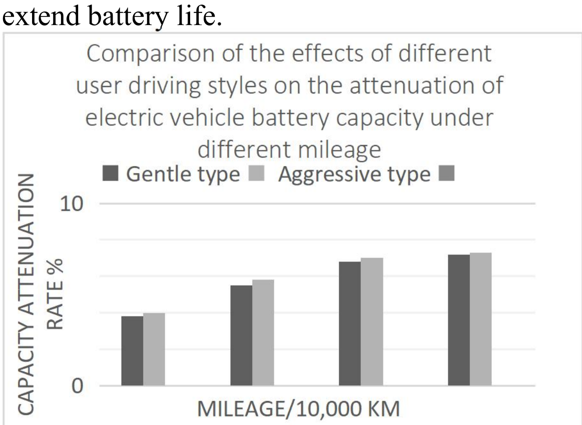

Figure 3. Comparison of the Effects of Different User Driving Styles on the Attenuation of Electric Vehicle Battery Capacity under Different Mileage

4. Conclusion

Based on the existing research data and data review, it is concluded that lithium batteries are widely used in electric vehicle batteries due to their high energy density and excellent battery life. At the same time, customers are advised to use slow charging in non-emergency situations and maintain a gentle driving style when using electric vehicles on a daily basis.

References

[1] He Hongwen, Yu Xiaojiang, Sun Fengchun, et al. Analysis of Power Characteristics of Electric Vehicle Motor Drive Systems [J]. China Journal of Electrical Engineering, 2006, 26(6):136-140.
[2] Ren Guizhou, Chang Siqin. An Energy-Efficient Regenerative Braking Method for Electric Vehicles [J]. Power Grid Technology, 2011, 35(1):164-169.
[3] Zhang Chengning, Wang Zaizhou, Song Qiang. Research on Noise Source Identification for Electric Vehicle Motor Systems Using Microphone Arrays [J]. China Journal of Electrical Engineering, 2008, 28(30):109-112.
[4] Zhou Yudong, Xu Haiping, Zeng Lili, et al. Design of Bidirectional Impedance Source Inverter Control System for Electric Vehicles [J]. China Journal of Electrical Engineering, 2009, 29(36): 101-107.
[5] Huang Mei, Huang Shaofang. Engineering Calculation Method for Harmonics in Electric Vehicle Charging Stations [J]. Power Grid Technology, 2008, 32(20):20-23.
[6] Li Na, Huang Mei. Harmonic Analysis of Power Systems After Connecting Different Types of Electric Vehicle Chargers [J]. Power Grid Technology, 2011, 35(1):170-174.
[7] Yan Hui, Li Gengyin, Zhao Lei, et al. Design and Implementation of a Monitoring System for Electric Vehicle Charging Stations [J]. Power Grid Technology, 2009,33(12):15-19.
[8] Tollefson J.Car industry： charging up the future[J].Nature,2008,456(7221):436-440.
[9] Ning Tao, Cui Yue. Discussion on lithium battery as a backup power source for important equipment and facilities in hospitals[J], China Hospital Architecture and Equipment, 2021(07)
[10] Zhang Yongfeng, Yu Yue, Zhang Bin, Zhao Jun, Xu Weijiang, Zhou Qingyuan, Li Quan.

Current situation and development of lead-acid batteries [J]. accumulator, 2021,58 (01)

[11] Xing Enhui, Wang Peizhen, Shang Xinbo, et al. Braking Energy Feedback Technology for Electric Vehicles [J]. Science Technology and Engineering, 2018, 18(25) : 116-127

[12] Xue Nuannuan, Chen Qingchen. Research on the current situation and development trend of new energy vehicle battery types [J]. Times Automobile. 2023 (19)

[13] Michael R? Big. Energy Management in Warehousing and Logistics [J]. Made in Hyundai 2022 (08).

[14] Tang Lihui, Zhang Liangang. Automatic container terminal horizontal transportation system, power system and charging scheme [J]. Water transport engineering. 2020 (06)

[15] Liang Haiqiang, He Hongwen, Dai Kangwei, Pang Bo. Analysis of the Influence of Electric Vehicle User Behavior on Battery Aging Based on Big Data [J]. Automotive Engineering . 2022 ,44 (08).

