Accuracy of range estimation of pure electric vehicles under compound conditions comparative analysis

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Abstract. In high and low temperature environments, especially in high-speed scenarios, the estimation accuracy of the range of electric vehicles is a pain point which is more concerned by consumers. Based on the China light-duty vehicle test cycle for passenger car, this paper deeply studies the estimation accuracy of the range of electric vehicles under different ambient temperature conditions. Further, a complex test cycle including long-distance in high-speed driving conditions is constructed, and the influence rule of the complex test cycle and high-speed vehicle speed on the estimation accuracy of cruising range is compared and analyzed through actual vehicle tests.

1. Introduction
With the continuous advancement of electric vehicle technology and rising consumer expectations for better electric vehicle products, electric car manufacturers will continue to improve and enhance product user experience, continue to promote electric vehicle product user satisfaction, cultivate product brand influence, and promote the healthy and sustainable development of the electric vehicle industry.

Electric vehicle users pay attention to various performances during the actual use of the vehicle. According to the report of the 2019 China New Energy Vehicle Industry Consumer Survey, the remaining display accuracy is one of the indicators that consumers are more concerned about but have lower satisfaction, which has a larger room for improvement. As shown in Figure 1[1].

![Figure 1. Consumer satisfaction scores for pure electric endurance indicators in 2019](image)

In high and low temperature environments, especially in high-speed scenarios, when the electric vehicle is in a state of high energy consumption, there will be a situation in which the displayed
mileage drops much faster than the actual mileage. This is the most concerned pain point in consumer research. The accuracy of cruising range estimation will affect the competitiveness of electric vehicle products to a certain extent, thus affecting the sales and promotion of electric vehicles.

Therefore, starting from the environment and composite conditions that affect the accuracy of the estimation of the cruising range of electric vehicles, facing the vehicle performance in real scenarios of consumers, through multi-dimensional objective testing, comparative analysis of pure electric vehicles in different scenarios and specific working conditions. The following table shows the difference in the accuracy of cruising range estimation, so as to provide consumers with a comprehensive and objective reference basis, and thus ease consumers’ anxiety about the mileage of electric vehicles[2-4], which has certain practical significance.

2. Research process.

2.1. Vehicle parameters
In this paper, a total of 4 vehicles are selected, all of which are conventional models, that is, the body length is greater than or equal to 4 meters. The vehicle parameters are shown in Table 1.

| Model | Curb quality (kg) | Ministry of Industry and Information Technology (km) | Battery capacity (kw•h) |
|-------|------------------|------------------------------------------------------|------------------------|
| Model A | 1508             | 401                                                  | 54                     |
| Model B | 180              | 400                                                  | 53                     |
| Model C | 2508             | 355                                                  | 70                     |
| Model D | 1574             | 416                                                  | 54                     |

2.2. Test method and data processing
In this paper, the working condition method of the laboratory is preferred to test the accuracy of the cruising range estimation. The battery life test is divided into normal temperature battery life (25℃), high temperature battery life (35℃) and low temperature battery life (-7℃). During the high-temperature or low-temperature endurance test, the air conditioner needs to be turned on. During the high-temperature test, the interior temperature must be maintained between 23° C and 25° C, and during the low-temperature test, the interior temperature must be maintained between 20° C and 22° C.

For the estimation accuracy of cruising range, this paper uses the determination coefficient $R^2$ to evaluate the goodness of fit evaluation [5], the calculation formula is:

$$R^2 = 1 - \frac{\sum (y_i - \hat{y}_i)^2}{\sum (y_i - \bar{y})^2}$$

Among them, $\hat{y}_i$ indicates the remaining mileage, $\hat{y}$ is the actual remaining mileage. The closer $R^2$ is to 1, the higher the accuracy of the cruising range estimation; otherwise, the worse the accuracy.

During the test, the parameter setting of the test environment scene, the test process and method, and the recording and processing of the test data refer to the "EV-TEST Management Rules (2019 Edition)"[6].


2.3. Construction of compound conditions
The basic driving conditions of the automobile are an important and common basic technology in the automobile industry, and the main benchmark for the calibration and optimization of various automobile performance indicators.

After analyzing the data characteristics of Chinese light vehicles and comparing the characteristics with other NEDC, WLTC and other operating conditions abroad, it is found that this classification method is not applicable to the actual situation in China. The existing NEDC operating conditions underestimate the energy-saving effect of new energy vehicles, and underestimate the energy-saving advantages of new energy vehicles such as braking energy recovery and idling start and stop. The main features of WLTC, such as idle time and average speed, are much different from the actual situation in China. By comparing the driving characteristics of new energy vehicles with traditional vehicles, it can be found that new energy vehicles share the road resources with traditional vehicles, the running characteristics are highly coincident, and there is a strong similarity in speed, acceleration, and sports history. Therefore, new energy vehicles have the foundation to use China light-duty vehicle test cycle for passenger car (CLTC-P). The speed curve of CLTC-P is shown in Figure 2.

![Figure 2. China light-duty vehicle test cycle for passenger car (CLTC-P)](image)

First of all, with the coverage and popularization of charging piles in high-speed service areas, consumers' desire and demand for driving electric vehicles at high speeds are becoming stronger and stronger. After investigation, it is found that consumers generally believe that the accuracy of the display mileage of electric vehicles at high speeds is low, and the decline in the display mileage is quite different from the actual mileage. Therefore, it is necessary to improve the accuracy of mileage estimation at high speeds is particularly prominent.

Secondly, with the continuous improvement and development of various technologies of electric vehicles, the emergence of vehicles with longer driving range has become possible. If the current full CLTC-P is used, it will not be conducive to the development of test work. A test method capable of quickly evaluating the driving range of electric vehicles should be developed to cope with the development trend of long driving range of electric vehicles.

Third, in the long-term evaluation, it is found that there are systematic errors in part of the evaluation process of the cruising range evaluation test. Increasing cruising range will overuse test resources. In order to ensure the representativeness and objectivity of the evaluation results, and to ensure the high stability of the test results, it is necessary to carry out the secondary development of the key evaluation technology for the range of electric vehicles to achieve high efficiency, high accuracy, and high coverage upgrades.

Therefore, based on the CLTC-P, this paper conducts a study on the test method of the driving range of electric vehicles, and constructs a composite test mode for rapid test and evaluation of the accuracy of the driving range estimation of electric vehicles including long-distance high-speed driving conditions. The composite operation method speed segment consists of 2 test cycle sections and 2 constant speed sections. Among them, DS1 and DS2 are test cycle sections, which are composed
of CLTC-P; CSSM and CSSE are constant speed sections, which are composed of higher constant vehicle speeds. Among them, the constant speed can be adjusted as needed. Figure 3 shows the speed curve of the composite test under constant speed of 100km/h.

Figure 3. Composite test conditions based on CLTC-P

3. Results of the accuracy test of range estimation

3.1. Test results of some models under full CLTC-P

Figure 4 shows the test results of the estimated accuracy of the cruising range of the three models under different CLTC-P under different temperature conditions. It can be seen from the figure:

Figure 4. Test results of some models under CLTC-P

Under normal temperature and high temperature environments, the determination coefficient $R^2$ of the three models is greater than 0.8, and the average values have reached 0.92 and 0.91, respectively, indicating that the vehicle's apparent cruising range fits the actual remaining range well. The cruising range estimation accuracy is high and the overall performance is good.

In a low-temperature environment, the average value of the determination coefficient $R^2$ for all vehicle models is 0.45, and the overall performance is poor. The determination coefficient $R^2$ of the vehicle model A and the vehicle model C is less than 0.20, indicating that the vehicle's apparent cruising range and the actual remaining range are poorly fitted. Model B still maintains a high accuracy. It can be seen that under low temperature environment, the accuracy differentiation between different models is more serious.

When testing in a low-temperature environment, it is required to turn on the air conditioner synchronously, which will consume a large amount of battery power[7-9], which will bring greater challenges to the accuracy of cruising range estimation. At the same time, the accuracy of estimated remaining mileage estimates varies greatly in different seasons, which may easily cause mileage anxiety to consumers.
3.2. Evaluation test results of $R^2$ based on composite condition method for estimation accuracy of cruising range

For the estimation accuracy of cruising range, the composite method is obviously equivalent to adding jump evaluation points (as shown in Figure 3).

Figure 5 shows the comparison of the test results of the estimated accuracy $R^2$ of the cruising range of the three models under the conditions of the whole CLTC-P and the composite conditions based on the constant speed section of 100km/h. As can be seen from the comparison in the figure, the accuracy of the estimated range $R^2$ of the three models in all single CLTC-P is shown in the table below. However, under the typical operating conditions of compound operating conditions, the accuracy of the range estimation $R^2$ has greatly decreased due to the existence of three trip points. The three models with the largest decrease in accuracy $R^2$ are model A (-15.30%) and the smallest are model B(-10.15%), with an average decrease 12.17%. It shows that the composite working conditions bring higher requirements to the accuracy of cruising range estimation.

Figure 6 shows the fitting comparison between the cruising range and the actual cruising range of the three models under normal temperature environment, based on the composite conditions at a constant speed of 100km/h. The curves fitted by the three sets of data all show the shape of the bell mouth, indicating that the accuracy of the estimated battery life in the car is low. In the later stage of the test, the fitting curves of the three vehicles gradually tended to converge, that is, the fit between the displayed endurance curve of each car and the actual endurance curve was getting better and better, indicating that the endurance mileage of the three cars was more and more It is close to the actual cruising range, and the accuracy of cruising range estimation is improved. Because these three models have a self-learning mode in the cruising range estimation strategy. This mode can correct the current
remaining mileage according to the previous mileage energy consumption, thereby improving the accuracy of displaying the remaining mileage estimation [10-12]. This model is currently one of the most important and widely used models for electric passenger vehicle mileage estimation.

3.3. Analysis of the effect of different constant speeds on the estimation accuracy of cruising range $R^2$ under compound conditions

When the vehicle is driving at a high speed, the range of the electric vehicle is greatly reduced due to factors such as motor efficiency and high power discharge[13-14], which brings more prominent mileage anxiety to the driver. This paper further studies and compares the comparison of test results based on the estimation accuracy $R^2$ of the cruising range based on the composite conditions of different speeds in the constant speed section.

Figure 7. The constant speed section is a composite condition of different vehicle speeds

Figure 7 shows the speed curve of the composite test conditions with the constant speed section set at 100km/h and 120km/h respectively. This article selects a hot-selling model D[1] with a relatively high market share, and conducts composite test tests at constant speeds with speeds of 100km/h and 120km/h, respectively, and shows the estimated accuracy of cruising range $R^2$. Evaluation and comparison were made, and the test results are shown in Figure 8 below.

Figure 8. Model D based on different constant speed test results under composite conditions

It can be seen from the above figure that the estimated accuracy of the cruising range $R^2$ of this model D is different under the composite conditions of different constant speeds. When the vehicle speed in the constant speed section was increased from 100km/h to 120km/h, the estimated accuracy $R^2$ of the cruising range showed a corresponding decrease of 9.13%. It shows that with the increase of the speed in the constant speed section, the estimation accuracy $R^2$ of the cruising range of electric vehicles shows a corresponding downward trend.
4. Conclusion
Based on the CLTC-P, this paper conducted a test and evaluation comparison of the estimation accuracy of the range of electric vehicles under full CLTC-P and composite conditions, and achieved certain research results.

1) The estimated accuracy of the cruising range of electric vehicles at different ambient temperatures is also different, with normal temperature being the best, high temperature being the second, and low temperature being the worst. Under the normal temperature environment, the determination coefficient $R^2$ of each model is generally greater than 0.8, and the average value reaches 0.92. In high-temperature environments, the difference in the accuracy of the estimates of various models has appeared. In a low temperature environment, the overall performance is poor and the differentiation is more serious. The average value of the determination coefficient $R^2$ of the three models is 0.45.

2) Because of the existence of three trip points and longer high-speed operating conditions in the composite conditions, higher requirements are required for the accuracy of the cruising range estimation. The average reduction in the mileage estimation accuracy $R^2$ of the three test vehicles is 12.17%. Tests show that the three vehicles have considered the self-learning mode in the calculation method of the meter display cruising range, which makes the meter display cruising range more and more close to the actual cruising range, which has a positive impact on improving the accuracy of the cruising range estimation.

3) In compound conditions, the vehicle speed at different constant speed sections directly affects the range estimation accuracy $R^2$. As the vehicle speed at the constant speed section increases, the range estimation accuracy $R^2$ decreases accordingly.

This article can further study the establishment of the corresponding cruising range estimation accuracy scoring rules, promote enterprises to improve cruising range estimation accuracy, provide consumers with more accurate mileage reference, and reduce mileage anxiety.

References
[1] 2019 China New Energy Vehicle Industry Consumer Survey Report.
[2] Jiang J, Ruan H, Sun B, et al. (2018) A low-temperature internal heating strategy without lifetime reduction for large-size automotive lithium-ion battery pack, Applied Energy,230:257-266.
[3] Wu J, Li T, Zhang H, et al.(2018) Research on Modeling and SOC Estimation of Lithium Iron Phosphate Battery at Low Temperature. Energy Procedia,152:257-266.
[4] Meng J, Ricco M, Acharya A B, et al. Low-complexity online estimation for LiFePO4 battery state of charge in electric vehicles. Journal of Power Sources, 395:280-288.
[5] Jia Junping. (2004) Statistics. Tsinghua University Press, Beijing, pp298-299.
[6] EV-TEST management rules (2019 version).
[7] Xia G D, Cao L, Bi G, et al. (2017) A review on battery thermal management in electric vehicle application. Journal of Power Sources,367: 90-105.
[8] Qin F, Qingfeng Xue, et al. (2015) Experimental investigation on heating performance of heat pump for electric vehicles at −20°C ambient temperature, Energy Conversion and Management, 102:39-49.ISSN 0196-8904.
[9] Lindgren J, Lund P.(2016) Effect of extreme temperatures on battery charging and performance of electric vehicles. Journal of Power Sources, pp:328: 37-45.
[10] Blanke H, Bohlen O, Buller S, et al.(2005) Impedance measurements on lead-acid batteries for state-of-charge, state-of-health and cranking capability prognosis in electric and hybrid electric vehicles. Journal of Power Sources, 144(2): 418-425.
[11] Fleischer C, Waag W, Bai Z, et al .(2013) On-line self-learning time forward voltage prognosis for lithium-ion batteries using adaptive neuro-fuzzy inference system. Journal of Power Sources, 243(1): 728-749.
[12] Sbarufatti C, Corbetta M, Giglio M, et al. (2017) Adaptive prognosis of lithium-ion batteries based on the combination of particle filters and radial basis function neural networks [J]. Journal of Power Sources, 344: 128-140.

[13] Liu K, Wang J, Yamamoto T, et al. (2017) Exploring the interactive effects of ambient temperature and vehicle auxiliary loads on electric vehicle energy consumption. Applied Energy, 227: 324-331.

[14] Demircali A, Sergeant P, Koroglu S, et al. (2018) Influence of the temperature on energy management in battery-ultracapacitor electric vehicles. Journal of Cleaner Production, 176: 716-725.