

Analysis on the difference of DC energy consumption of electric vehicles under repeat cycles

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Abstract. In order to avoid the problem of too many AC energy consuming for the standard electric vehicle driving range test, the DC energy consumption test can be used to obtain the energy consumption of the test cycle at any time period and estimate the driving range. However, the rationality of intercepting part of the circulating DC energy consumption to estimate the whole process still lacks sufficient experimental support. Therefore, in this paper, two different electric vehicle prototypes were selected, and a complete energy consumption test experiment was carried out according to the standard test process. Through the test of DC energy consumption, the difference characteristics of electric vehicle driving braking energy and energy consumption under repeated cycles were analyzed. The fluctuation range provides data support for the use of DC power to evaluate the energy consumption of electric vehicles

1 Introduction

In recent years, the announcement of global EV policies has stimulated the growth of EV sales in major automobile markets ^{[1][2]}. Among them, China has become the world's largest electric vehicle production and sales country. In 2020, the production and sales will be 1.366 million and 1.367 million respectively, with year-on-year growth of 7.5% and 10.9%, respectively. In addition, the development and promotion of electric vehicles has become an important measure to solve energy and environmental problems in many countries ^[3]. However, with the improvement of the ownership rate, more and more consumers are worried about the energy consumption and driving range of electric vehicles ^{[4][5]}. To that end, accurate EV mileage announcements can help increase consumer acceptance of EVs.

The calculation of standard energy consumption rate is obtained from laboratory tests or simulations through standard test cycle experiments (NEDC, FTP75, WLTC, etc.) ^[6].

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However, in the energy consumption test method of electric vehicles, the test time of a single vehicle is too long, and the test results can only be expressed through the charging results of AC charging piles. Once abnormal conditions occur in the test process, it will need to be re-tested, which will increase the test cost.

Therefore, if combined with the instantaneous DC energy consumption at the bus end of the battery of electric vehicles in the test process, it is possible to effectively reduce the test cost, reduce the number of test cycles, and describe the energy consumption level of vehicles through the energy consumption results of a few cycles.

In this paper, the energy consumption test of electric vehicles was carried out according to GB/T 18386-2017 "*Electric Vehicle Energy Consumption Rate and Driving Range Test Method*", and the DC energy consumption during the vehicle test was collected to study the difference between DC energy consumption under repeated cycle conditions in a complete electric vehicle energy consumption test.

2 Test method

1.1 test conditions introduction

In this paper, driving conditions for passenger vehicles (CLTC-P) in the test cycle of CLTC vehicle are adopted as the test cycle, as shown in Figure 1.

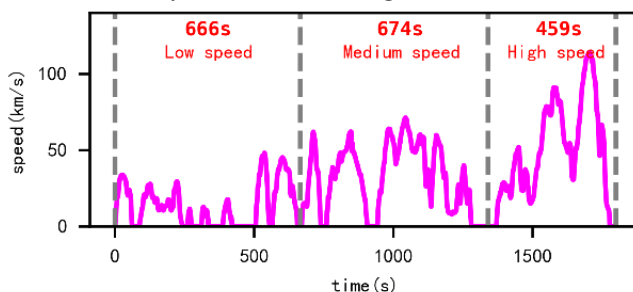


Fig. 1. CLTC-P.

CLTC-P gradually replaced NEDC to become the mainstream test cycle in domestic passenger vehicle research. CLTC-P test cycle is more rigorous than NEDC test cycle, with more acceleration and deceleration processes that are in line with actual driving, and there is obvious low speed, medium speed and high speed ranges.

2.2 Test equipment procedure

This paper is strictly in accordance with GB/T 18386-2017 "*Electric Vehicle Energy Consumption rate and driving range test method*" test process for two test samples. During the test, the test temperature was maintained at 20-30°C. The electric vehicle is tested on the chassis dynamometer using the CLTC-P cycle until the speed and time tolerance requirements in the test criteria cannot be met and the test is stopped. During the test, a stop of (10±1) minutes was allowed after every 6 test cycles. During the stop, the vehicle start switch should be in the "OFF" state, close the hood, close the test-bed fan, release the brake pedal, and cannot use the external power source to charge.

In the standard energy consumption test experiment, only the charging energy obtained from the AC charging pile and the vehicle traveling distance of dynamometer were recorded to calculate the energy consumption rate. In this paper, the power analyzer is used

to collect the instantaneous energy consumption parameters of the vehicle battery bus to calculate the DC energy consumption of the test cycle.

2.3 Data processing procedure

The energy consumption experimental data is mainly divided into two parts. One part is the energy consumption data of the battery bus recorded by the power analyzer, and the other part is the vehicle speed data recorded by the chassis dynamometer.

The sampling frequency of the test data of the two parts is 10Hz. In order to reduce the computational complexity and data storage space, the data is resampled at the interval of 1 second. The energy consumption data of the battery bus and the data of the chassis dynamometer are connected through the sampling timestamp as the foreign key, so as to obtain the complete test data, as shown in Figure 2.

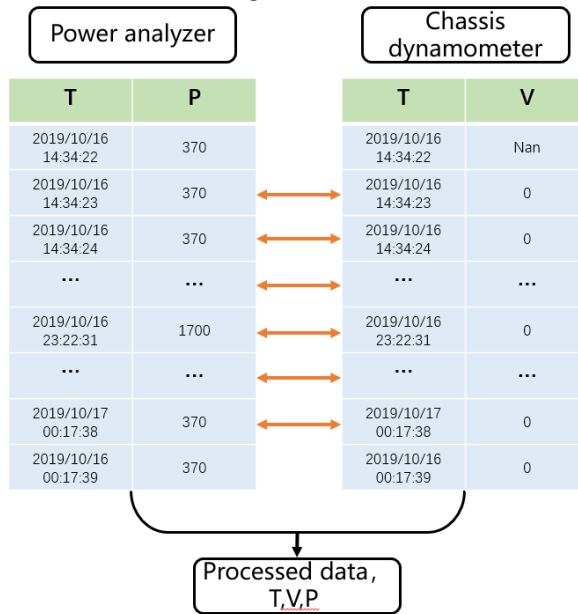


Fig. 2. Combined data processing.

The combined test data includes time stamp T (s), real-time speed V (km/s) and real-time power P (w). Fig. 3 shows the complete speed curve of the two test sample vehicles. As can be seen from Fig. 3, both of the two test samples completed 30 CLTC-P, and actively stopped the test because the speed tolerance did not meet the test requirements. There was an incomplete CLTC-P at the end of the speed curve. Due to the signal instability of the sampling equipment in the initial stage and the asynchronous sampling between the power analyzer and the chassis dynamometer, as shown in Fig. 4, the power and speed data of the first test cycle of the two test samples were incomplete.

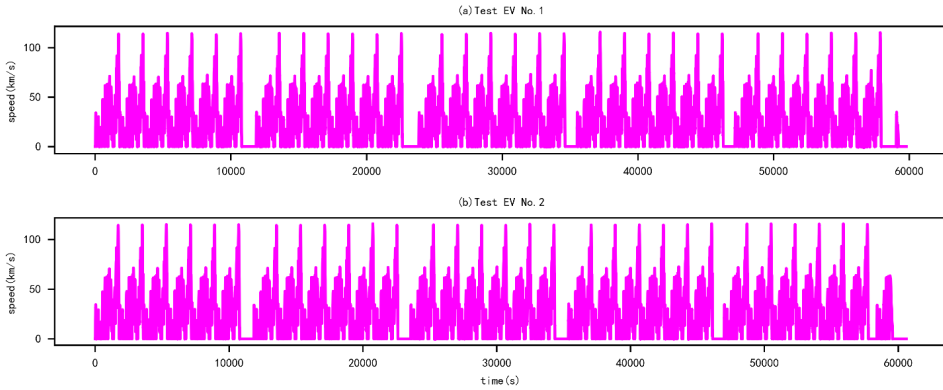


Fig. 3. Complete test velocity curve.

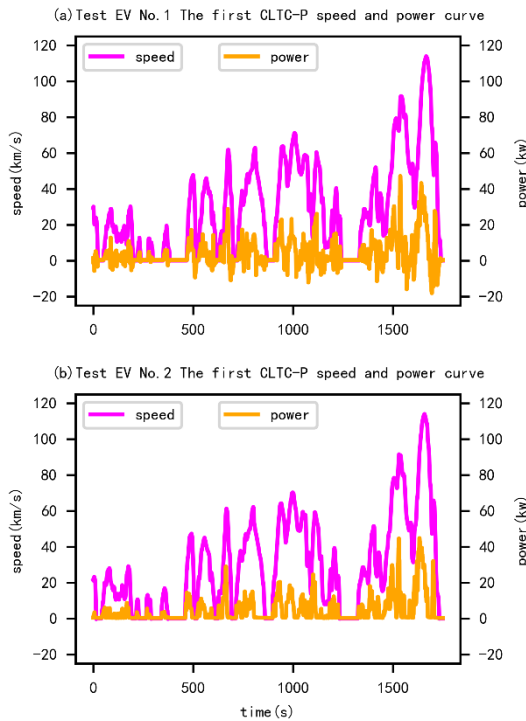


Fig. 4. Missing data of the test sample vehicle.

As can be seen from Fig. 4 (a), there is a brief lack of speed and power data in the sample vehicle. It can be seen from Fig. 4 (b) that sample car 2 also has the problem of data loss, and the vehicle of sample car 2 is in CD mode in the first test cycle without braking recovery. Therefore, the first CLTC-P test results and the last incomplete test cycle were excluded during the data analysis phase, retaining a total of 29 complete test cycle data.

The driving distance and energy consumption corresponding to each test cycle will be solved by using the discrete Simpson integral formula and expressed as:

$$I = \int_b^a f(x)dx(a < b)$$

In each unit, a parabola is used to approximate the curve of the function $f(x)$. Therefore, the discretization of the definite integral can be expressed as:

$$I = \int_b^a f(x) dx \approx \frac{b-a}{6n} \left(y_0 + y_{2n} + 4(y_1 + y_3 + \dots + y_{2n-1}) + 2(y_2 + y_4 + \dots + y_{2n-2}) \right)$$

In the formula, i is the result of integration, n is the total number of discrete items, b and a are the upper and lower limits of integration respectively, $y_i (i=1,2,3\dots)$ represents the i th values.

3 Result and analysis

Firstly, the relationship between the overall energy consumption and the average energy consumption of 29 CLTC-P driving cycles of two test samples was analyzed. As can be seen from Figure 5, even the same test cycle energy consumption of the same vehicle still fluctuates.

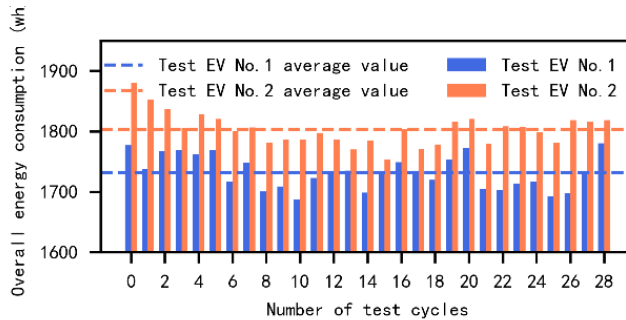


Fig. 5. Comparison results of overall energy consumption between cycles.

As can be seen from the relative error distribution in Fig. 6, the maximum relative error of sample car 1 was 2.79%, which occurred in the 29th test cycle. The maximum relative error of sample car 2 was 4.56%, which occurred in the first test cycle. At the same time, both vehicles had the same trend of energy consumption. At the beginning of the test, the cycle energy consumption was high, at the middle of the test, the cycle energy consumption began to be lower than the average, and at the end of the test, the cycle energy consumption was high again. By analyzing the change of overall energy consumption, it can be concluded that the energy consumption of the same vehicle in the same test cycle is not exactly the same. Since the energy consumption of the test cycle is the instantaneous energy consumption of the collected battery bus, the overall energy consumption of each cycle includes the energy consumption in the driving process and the energy recovery in the braking recovery process. Therefore, this paper further analyzes the change of vehicle driving energy consumption, as shown in Fig. 7, and the change of braking recovery energy consumption, as shown in Figure8.

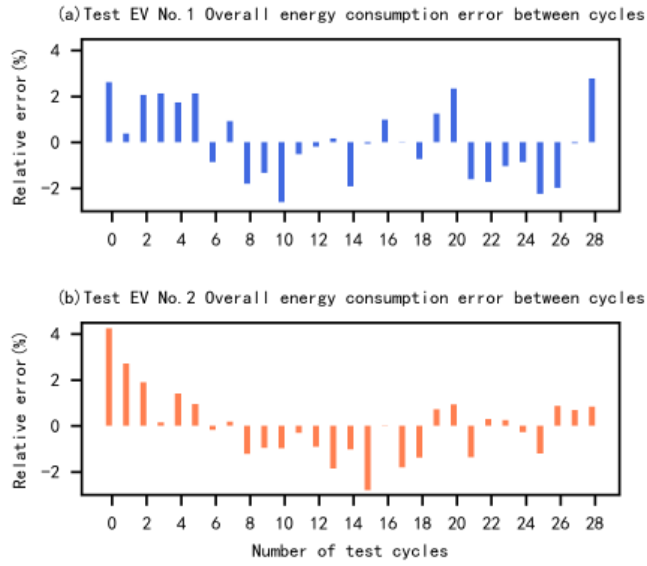


Fig. 6. Relative error of overall energy consumption between cycles.

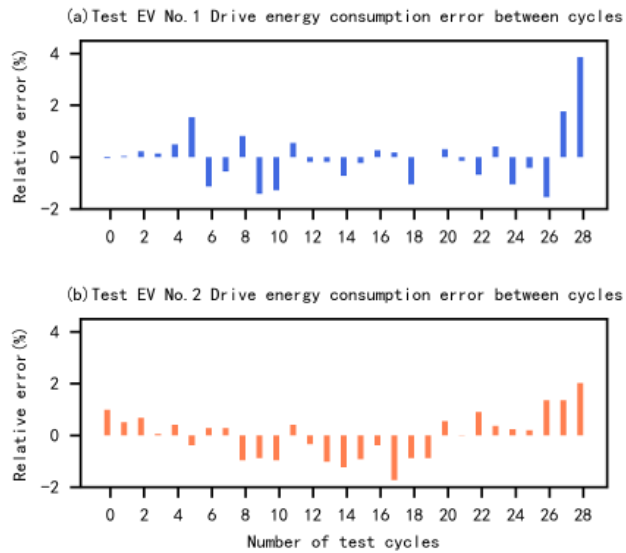


Fig. 7. Relative error of drive energy consumption between cycles.

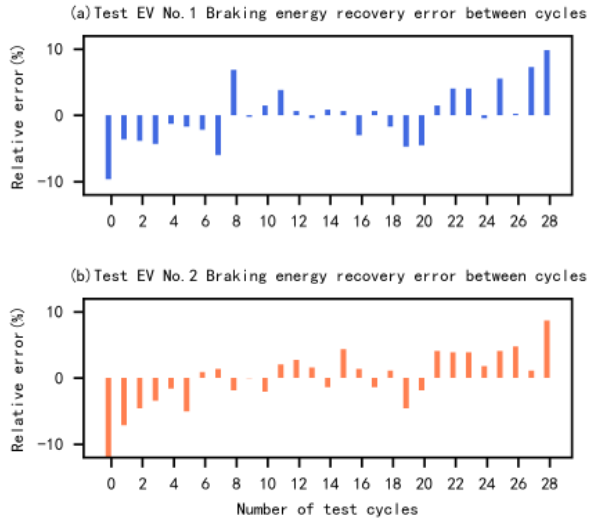


Fig. 8. Energy recovery error by braking between cycles.

The energy consumption in the driving process refers to the energy output by the motor of the test vehicle in the test cycle, which is mainly the energy consumed to maintain the target speed to overcome the roll resistance and wind resistance. The braking recovery energy refers to the energy recovered from the battery after overcoming the sliding resistance, transmission, motor and other losses during the deceleration process of the test vehicle in the test cycle. It can be seen from Fig. 7 that the change of energy consumption of the two test vehicles is obviously less than the change of the overall energy consumption. Except that the energy consumption error of the 29th test cycle of the first test vehicle is 3.8%, the energy consumption error of the other two test samples are all less than 2%. At the same time, the largest overall energy consumption error of the sample vehicle 1 was also in the 29th test cycle. Therefore, the speed curve and power of the test cycle No.20 with the smallest driving energy consumption error were compared with that of the test cycle No. 29, as shown in Fig. 9. In Fig. 9 (a), the velocity curves of the two test cycles are basically identical, while in Fig. 9 (b), the power curves of the two test cycles have obvious deviations at the position of the red box. The peak of No. 29 test cycle increases significantly at the high-power moment, and there are also obvious deviations at some positions where the output power should be 0. The cause of the deviation is probably related to the control of the motor under the low voltage condition of the battery.

However, the variation of braking recovery energy in Fig. 8 is more obvious in the whole test process, with a fluctuation range of 20%. The two test sample vehicles had the same trend variation. The recycled energy of cyclic braking in the initial test stage was significantly lower than the mean value of the recycled energy, the error in the middle test period was significantly reduced, and the recovered energy of braking in the late test period was increased and significantly higher than the mean value. The change trend indicates that the change of braking recovery energy consumption has obvious correlation with the vehicle's remaining electric quantity.

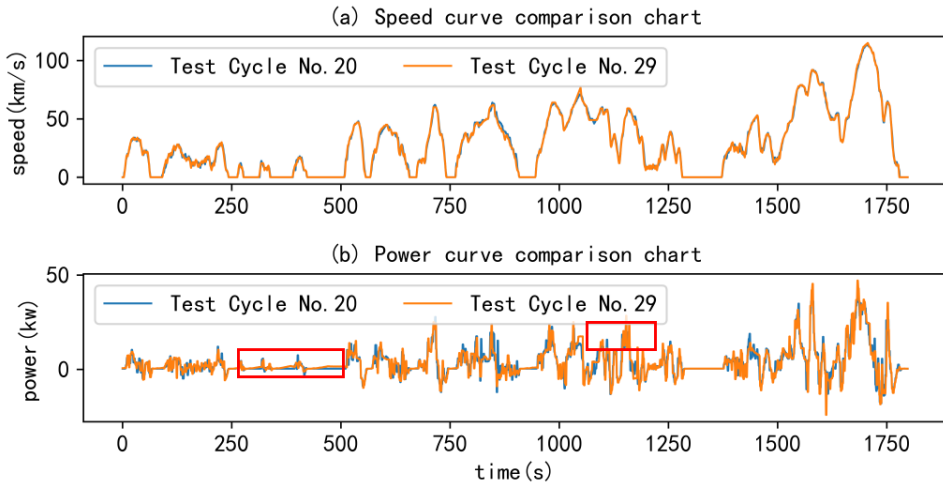


Fig. 9. Comparison diagram of speed and power of the vehicle sample one.

4 Discussion

From the DC energy consumption results of the test cycle in the second part, it can be seen that there are also DC energy consumption results between cycles of the same vehicle

Therefore, the DC energy consumption rate of a certain cycle in the test process cannot be randomly used to replace the AC energy consumption rate test result. Therefore, the results obtained when the DC energy consumption rate is used should not provide a single value like the test AC energy consumption rate, but take the range value of energy consumption as the expression. As shown in Fig.10, the normal distribution diagram of the cycle energy consumption rate of two test sample cars is shown. Figure 10 shows the range of 95% confidence intervals of two test sample vehicles. The DC energy consumption rate (wh/km) of CLTC-P of sample vehicle 1 is [117.2,124.5], and the DC energy consumption rate (wh/km) of CLTC-P of sample vehicle 2 is [121.9,128.7]. Therefore, combined with the battery capacity of the vehicle, the range value of the vehicle's driving range can be provided to the driver, and the driver can estimate the remaining driving range of the vehicle according to the actual situation. Compared with the single driving range obtained through the AC energy consumption rate, it is more meaningful in practical application.

However, in this paper, there is still a need to further research and perfect aspects, such as determined by the trial while the same cycle there is a difference between the DC power consumption, but there is no contrast experiment was carried out energy consumption in communication, not sure the same vehicle in multiple communication experiment result difference how much energy consumption, energy consumption compared with the DC power consumption results which the error of the solution is smaller, this part of the content needs to be determined in the subsequent experiments.

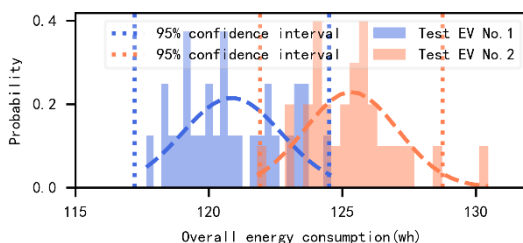


Fig. 10. The DC energy consumption rate is normally distributed.

5 Conclusion

In this paper, the difference between the energy consumption of electric vehicle and that of circulating DC is analyzed.

1) There are differences in energy consumption between electric vehicles and circulating DC. The largest deviation mainly occurs in the test stage of full power and low power, and the difference in energy consumption of most cycles is within $\pm 2\%$.

2) Most of the driving energy consumption differences of electric vehicles in repeated cycles are also within $\pm 2\%$, but when the battery power is very low, the driving energy consumption of the vehicle will be significantly increased.

3) The fluctuation of braking recovery energy of electric vehicles in repeated cycles is more obvious, and the range can reach $\pm 10\%$. The braking recovery energy gradually increases with the decrease of battery power.

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