Research on the influence of air conditioning energy consumption on brake energy recovery contribution rate based on operating conditions

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Abstract: In the process of braking energy recovery, for the vehicle model that the recovered part of the energy is directly supplied to the air conditioner, there is a lack of research on the influence of air conditioning energy consumption on the measurement method of braking energy recovery contribution rate in the existing test methods. This paper studies the influence of air conditioning energy consumption on braking energy recovery contribution rate under NEDC and CLTC-P cycles. The test results show that for NEDC and CLTC-P cycles, the air conditioning energy consumption has little effect on the contribution rate of braking energy recovery under the same external temperature, solar radiation intensity and target temperature inside the vehicle. The above viewpoints can be used as reference for testing researchers when testing the contribution rate of vehicle braking energy recovery.

1. Introduction

There are many energy consumption indicators for electric vehicles. The more energy consumption, the longer the electric vehicle's endurance and mileage will be affected. Therefore, many key energy saving technologies have been developed. One of the key technologies, the braking energy recovery technology, can improve the use economy of electric vehicles. The energy consumption of the motor is reduced by this braking energy saving technology[1].

In[2], the contribution evaluation method of regenerative braking to energy efficiency improvement of electric vehicles is discussed. In[3], the evaluation method of regenerative energy contribution is introduced, the energy flow of electric vehicle is analyzed, and the chassis dynamometer is tested under typical driving cycle with three control strategies. In[4], the influence of accessories on energy efficiency of different hybrid electric vehicle topologies is discussed, but the influence of accessories on braking energy regeneration system is not discussed. In[5], Teresa donateo and other researchers analyzed the influence of vehicle mileage and brake energy recovery under air conditioning and radio operation conditions through real vehicle test. However, this paper mainly focuses on vehicle test, and does not introduce the mechanism analysis of accessories on braking energy regeneration system, but only simple test results.

According to the existing research on traditional vehicles, the total energy consumption of accessory system accounts for about 15% of the total fuel consumption, while for cities near the equator and in hot climate, the proportion is relatively large, reaching about 50%[3]. Research shows...
that compared with traditional vehicles, the energy efficiency of electric vehicles is more sensitive to
the energy consumption of accessories\(^5\). However, in the existing brake energy recovery test process,
there is a lack of research on the influence of air conditioning energy consumption on the test results,
especially the research on the test method of brake energy recovery contribution rate, so it is necessary
to further study.

2. Influence of cycle on contribution rate of braking energy recovery
Please follow these instructions as carefully as possible so all articles within a conference have the
same style to the title page. This paragraph follows a section title so it should not be indented.

According to the content of \(^6\), the driving or braking power of the whole vehicle can be expressed as:

\[
P_t = (mgf + 0.5C_DApv^2 + \left( m + \frac{6I_w}{r^2} \right) \frac{dv}{dt} )v
\]

(1)

In the above formula, \( m \) is the vehicle mass, \( g \) is the acceleration of gravity, \( f \) is the rolling
resistance coefficient, \( \alpha \) is the road slope, \( C_D \) is the air resistance coefficient, \( A \) is the windward area;
\( I_w \) is the wheel inertia, \( v \) is the speed. From the above formula, the energy formula of vehicle driving
or braking can be deduced:

\[
E = \int P_t \, dt = \int \left( (mgf + 0.5C_DApv^2 + \left( m + \frac{6I_w}{r^2} \right) \frac{dv}{dt} )v \right) \, dt
\]

(2)

According to the above formula, the driving or braking energy \( E \) of the whole vehicle is a
multivariate function:

\[
E = f(f, C_D, A, m, I_w, r, v, \frac{dv}{dt})
\]

(3)

It can be seen from the above formula that \( f, C_D, A, m, I_w, r \) are vehicle parameters, and \( v, \frac{dv}{dt} \)
are cycle parameters, the energy consumed in the process of driving or braking mainly depends on two
types of parameters: vehicle and cycle.

In the cycle, the speed and acceleration are dynamic, so the output power is also dynamic. In order
to analyze the driving and braking energy of unit mileage and unit mass under different cycle
conditions, the following derivation is made.

In this paper, the energy in driving process and braking process is considered respectively, Let
\( m_e = m + \frac{6I_w}{r^2} \), and \( S \) represents the total mileage under cycle conditions. Thus, the driving energy of
unit mileage unit mass \( \frac{E_f}{mS} \) and braking energy unit mass unit mileage \( \frac{E_b}{mS} \) can be obtained
respectively as follows:

\[
E = \int P_t \, dt = \int \left( (mgf + 0.5C_DApv^2 + \left( m + \frac{6I_w}{r^2} \right) \frac{dv}{dt} )v \right) \, dt
\]

(4)

The calculation formula of driving and braking energy of electric city bus under cycle conditions is
as follows:

\[
\frac{E_f}{mS} = \alpha f + \beta \frac{C_D A}{m} + \gamma \frac{m_e}{m}
\]

(5)
\[ \frac{E_d}{mS} = \gamma \frac{m_e}{m} - \alpha \int f - \beta \frac{C_{pA}}{m} \]

(6)

In the above formula, \( \alpha, \beta, \gamma \) is the calculation coefficient of driving energy, \( \dot{\alpha}, \beta \) is the calculation coefficient of braking energy, and the calculation expression of variable is:

\[ \alpha = \frac{\int g v dt}{S} \]

(7)

\[ \beta = \frac{\int 0.5 \rho v^3 dt}{S} \]

(8)

\[ \gamma = \frac{\int v dt}{S} \]

(9)

\[ \dot{\alpha} = \frac{\int g v dt}{S} \]

(10)

\[ \dot{\beta} = \frac{\int 0.5 \rho v^3 dt}{S} \]

(11)

It can be seen from the above formula that the braking energy per unit mileage and unit mass is closely related to vehicle parameters, vehicle speed and acceleration under cycle conditions.

3. Vehicle test and test data analysis

3.1 Test preparation

Environmental simulation test of automobile air conditioning is a kind of dynamic performance test, which can reproduce any environmental conditions, repeat the test, carry out the real system test, organize the test scheme, and observe and analyze in the test with high safety[7].

In this paper, the refrigeration performance of the air conditioning system is mainly tested, so only the high temperature climate simulation test is carried out. The principle structure of the environment chamber of the simulation environment test is shown in Figure 1. Refer to table 1 for the parameters of vehicles used in the test.

| Parameter                  | Value |
|----------------------------|-------|
| Curb weight (kg)           | 1648  |
| Maximum torque of motor (N.m) | 290   |
| Maximum power of motor (kw) | 132   |
Maximum speed (km / h) 156
Total energy of power battery pack (kW.H) 54.75
Maximum range (km) 410
Power consumption per 100 km (kWh / 100km) 14.7

Humidity simulation system
Centrifugal humidifier

Humidity control
Solar radiation system
Thyrstor voltage regulator

Solar radiation intensity control
Wind speed simulation system
Blower

Wind speed control
Temperature control
Humidity simulation system
Air conditioning unit, heater

Fresh air system
Exhaust emission system

Figure 1. Structural schematic diagram of vehicle test chamber in simulated environment

Other test precautions refer to the requirements of QCT 658-2009 road test method for performance of automotive air conditioning and refrigeration system.

3.2 Analysis of test results
In order to further study the influence of energy consumption of automobile air conditioning system on the test method of braking energy recovery contribution rate, the test results under NEDC and CLTC-P cycles are compared and analyzed.

Considering the energy consumption of air conditioning system, the calculation formula of braking energy recovery contribution rate of pure electric vehicle is [8]:

$$\xi_2 = \frac{E_{\text{reg}, as} + \eta_{\text{discharge}} \eta_{\text{charge}} \cdot E_{\text{reg}, es}}{E_{\text{reg}} + E_{\text{es, out}}' - E_{\text{es, in}}'}$$

(12)

In the above formula, $E_{\text{reg}, as}$ is the feedback energy of the motor driving the accessory system, $E_{\text{reg}}$ is the bus electric energy recovered by the motor through the transmission system and the motor during the braking feedback process, $E_{\text{reg}, es}$ is the part of the energy fed back by the motor braking that is charged into the energy storage device, $E_{\text{es, out}}'$ is the total discharge energy of the battery, $E_{\text{es, in}}'$ is the total charging energy of the battery, $\eta_{\text{discharge}}$ is the average discharge efficiency of the battery under the cycle condition, $\eta_{\text{charge}}$ is the average charging efficiency of the battery under the cycle condition.

If the energy consumption of air conditioning system is not considered, the calculation formula of braking energy recovery contribution rate of pure electric vehicle is simplified as follows [8]:

$$\xi_1 = \frac{\eta_{\text{charge}} \cdot \eta_{\text{discharge}} \cdot E_{\text{es, in}}'}{E_{\text{es, out}}'}$$

(13)

In the process of analyzing the problem, a pure electric passenger car is selected as the test object, and the specific parameters of the vehicle are shown in Table 1. The test and comparative analysis of NEDC and CLTC-P cycles are carried out. During the test process, the battery voltage, current and motor real-time torque and other parameters change as shown in Figure 3 and Figure 4.
Table 2 lists the total energy of battery charge and discharge, the total energy of motor feedback, the energy consumption of air conditioning system in the process of driving and braking under the single cycle condition of NEDC and CLTC-P, as well as the contribution rates $\zeta_1$ and $\zeta_1$ of braking.
energy recovery calculated according to formula (13) and formula (12). Among them, the charging and discharging efficiency of the battery is taken as 0.95, that is \( \eta_{\text{charge}} = \eta_{\text{discharge}} = 0.95 \).

| Flow energy of each component \((10^6 J)\) | NEDC condition | CLTC-P condition |
|------------------------------------------|----------------|------------------|
| Battery output total energy              | 8.0808         | 9.7354           |
| Battery input total energy               | 1.5            | 3.345            |
| Motor braking feedback total energy      | 1.55           | 3.4              |
| Total energy consumption of air conditioning | 1.97      | 2.3749           |
| \( \zeta_1 \)                          | 16.75%         | 31.52%           |
| \( \zeta_2 \)                          | 17.26%         | 31.9%            |

Figures 2, 3 and table 2 are the data obtained under the condition of 35°C outside the vehicle, 45°C radiation temperature and 27°C interior temperature. From the above chart, it can be concluded that:

(1) Compared with NEDC cycle, CLTC-P cycle has greater contribution rate of braking energy recovery. The main reason is that CLTC-P cycle has higher energy recovery demand than NEDC cycle in the middle and low speed section, which reduces the acceleration demand and increases the deceleration proportion, that is to say, it improves the influence of braking energy recovery condition, and finally makes CLTC-P cycle have higher energy recovery demand.

(2) Both NEDC cycle and CLTC-P cycle data indicated the contribution rate of braking energy recovery calculated by the calculation method considering motor braking recovery and energy flow between air conditioners is higher than that calculated by neglecting air conditioning energy consumption and energy flow.

The reason is that when the electric braking feedback is considered in the calculation method including air conditioning energy consumption, the energy directly driving the air conditioner does not need to go through the charging and discharging process of the battery again, thus reducing the energy loss.

(3) Both NEDC cycle and CLTC-P cycle data indicated the energy consumption of air conditioning system in regenerative braking is very small, In the actual measurement process, the influence of air conditioning energy consumption on the contribution rate of braking energy recovery can be ignored.

4. Summary
Under the condition of 35°C outside the vehicle, 45°C radiation temperature and 27°C interior temperature, compared with NEDC cycle, CLTC-P cycle has greater contribution rate of braking energy recovery, both NEDC cycle and CLTC-P cycle data indicated the energy consumption of air conditioning system in regenerative braking is very small, the contribution rate of braking energy recovery calculated by the calculation method considering motor braking recovery and energy flow between air conditioners is higher than that calculated by neglecting air conditioning energy consumption and energy flow.
In the next step, the research on the impact of air conditioning energy consumption on braking energy recovery contribution rate can be further analyzed for different new energy vehicles, or summarize the rules of more cycles, so as to improve the research on the contribution rate of air conditioning energy consumption on braking energy recovery.

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