Research on the method of coasting resistance for light-duty vehicles at various altitudes

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Abstract. In order to obtain the coasting resistance of vehicles at different altitudes and temperatures, experiment selects three different types of vehicles, and conducts altitude coasting resistance research tests at four altitudes and temperatures. The results show that the modified coasting resistance method can accurately correct the coasting resistance of the vehicle under the condition of 0 meters and 20 °C to different altitudes and temperatures, while the error is controlled within 6%. The modified coasting resistance method can be kept within 4% in most cases, and it is applicable to different types of vehicles.

1 Introduction

At present, it is necessary to know the road coasting parameters of the vehicle under the corresponding altitude and temperature environment before using various laboratories with chassis dynamometers (such as room temperature, low temperature and altitude environment test laboratories) to test the vehicle performance. A variety of vehicle tests can be carried out[1-4], after the vehicle is subjected to a coasting test on the chassis dynamometer to obtain the coasting parameters of the vehicle's chassis dynamometer.

Only a coasting test at an altitude of 0 meters and a temperature of 20 °C is required in China's automobile emission regulation. For the 20°C room temperature laboratory test, the resistance can be used directly [5-9], and for the test when the temperature deviates greatly from 20°C, the above-mentioned resistance is usually multiplied by a coefficient [1,2] based on experience. This method is simple and easy to use, but the error is large. When the altitude is not 0 meters, the coasting resistance of the car needs to be tested at the corresponding altitude and temperature. However, this method is costly and it is difficult to find a suitable coasting test site.

In order to solve the problem of obtaining vehicle coasting resistance data under the above-mentioned different test conditions, this paper appropriately modified the resistance correction method obtained based on the vehicle’s theoretical coasting resistance formula in the US regulations SAE J1263 to make it corrected to different altitude and temperature conditions based on 0-meter altitude and the coasting resistance at 20°C. Three different

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types of test vehicles were selected for road coasting tests at four altitudes and four temperatures. The accuracy and adaptability of the correction method were verified by comparing the actual resistance of the vehicle with the theoretical correction resistance.

2 Coasting resistance correction method

The coasting resistance of a car is mainly composed of rolling resistance, air resistance and slope resistance, which are related to air density, air temperature, wind speed, road conditions and tire pressure[9]. The coasting resistance is only related to air density, air temperature and wind speed under the conditions of the vehicle coasting test[3]. So the vehicle coasting resistance can be corrected in these three aspects. The specific theoretical formula and correction method of the vehicle’s road coasting resistance are as follows.

2.1 Theoretical calculation

In the coasting test, according to the principles of mechanics, it can be concluded that vehicle coasting resistance is composed of rolling resistance and air resistance. The formula is as follows.

\[
F = -M \frac{dV}{dt} = \mu W + \frac{1}{2} \rho C'_D A [(V + S v_x)^2 + v_y^2]
\]

F —— Coasting Resistance;
M —— the mass of the car;
\(\mu\) —— rolling resistance coefficient;
W —— Car gravity;
\(\rho\) —— Air density;
\(C'_D\) —— Air resistance coefficient when the deflection angle is non-zero;
A —— Windward area of vehicle;
V —— Speed;
vx —— Wind speed component parallel to the direction of the vehicle;
v_y —— Wind speed component perpendicular to the direction of the vehicle;
S —— When vx and V direction are the same, it is -1, otherwise 1.

The rolling resistance coefficient is composed of the following two parts. The formula is as follows.

\[
\mu = \mu_0 (1 + \mu' V^2)
\]

\(\mu_0\) —— Rolling resistance coefficient independent of vehicle speed;
\(\mu'\) —— Rolling resistance coefficient related to vehicle speed.

Air resistance is the result of the combined effect of the resistance experienced by the car when driving at a speed of V and the force of natural wind on the car. \(C'_D\) can be expressed by the following formula.

\[
C'_D = C_D + k \sin^2 \psi
\]

\[
= C_D + k v_y^2 / [(V + S v_x)^2 + v_y^2]
\]

\(\psi\) —— The deflection angle formed by the combined action of vehicle speed and wind speed;
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2.1 Theoretical calculation
In the coasting test, according to the principles of mechanics, it can be concluded that vehicle coasting resistance is composed of rolling resistance and air resistance. The formula is as follows.

\[ F = -M \frac{dV}{dt} = \mu_0 W + \frac{1}{2} \rho C_D A v_x^2 + \frac{1}{2} \rho A (C_D + k)v_y^2 + (\mu_0 \mu W + \frac{1}{2} \rho C_D A)V^2 + \rho C_D A S v_x V \]  

(4)

In the actual car coasting resistance test, the car's average running resistance can be determined by multiple sets of tests using the forward and reverse twice on the same road test taxi as a group. So the coasting resistance of the car can be expressed as follows:

\[
\begin{align*}
F &= f_0 + f_2 V^2 \\
\mu_2 &= \mu_0 W + \frac{1}{2} \rho C_D A \\
\mu_0 &= \mu_0 W + (f_2 - \mu_0 W) v_x^2 + \frac{1}{2} \rho C_{DY} A v_y^2 
\end{align*}
\]  

(5)

2.2 Vehicle coasting resistance required by regulations
\[ F = \frac{2 \times M \times \Delta V}{3.6 t} = f_0 + f_2 V^2 \]  

(6)

\( \Delta V \) —— The difference in speed between the two recorded data in the car coasting test; 
\( t \) —— The time which takes to decelerate from \((V + \Delta V)\) to \((V - \Delta V)\) in the car coasting test.

2.3 Coasting resistance coefficient \( f_0 \) and \( f_2 \)
After calculating the actual coasting resistance of the car according to the left half of formula (6), the least square method can be used to calculate the coasting resistance coefficients \( f_0 \) and \( f_2 \) in formula (6).

2.4 Coasting resistance under actual test conditions
The wind speed at the coasting test site will have a greater impact on the rolling resistance of the car. The calculation formula for the rolling resistance of the car when the wind speed is not zero in the coasting test can be obtained by formula (5).
\[ \mu W = (f_0 - f_2 v^2_i - \frac{1}{2} \rho C_{Dy} A v^3_i)/(1 - \mu v^2_i) \]  

(7)

Unless the manufacturer has specific requirements, the coefficients in the above formula are expressed as follows:

\[ \mu' = 19 \times 10^{-6} \ (km / h)^2 \]  

(8)

\[ C_{Dy} = 0.8181 (m / s)^2 / (km / h)^2 \]  

(9)

Temperature mainly affects the rolling resistance of a car, which can be corrected by a temperature correction coefficient \( k_t \). The formula is as follows.

\[ f'_0 = \mu'_0 W [1 - k_t (T - T_0)] \]  

(10)

\( T \) —— Air temperature under proposed correction conditions;  
\( T_0 \) —— Standard temperature (20°C).

Unless the manufacturer has specific requirements, the coefficients in the above formula are expressed as follows:

\[ k_t = 8.6 \times 10^{-3} / ^\circ C \]  

(11)

The coefficient term of \( V_2 \) of the vehicle coasting resistance formula (4) can be corrected to the actual environmental state by using the following formula:

\[ f'_2 = (\rho / \rho_0)[f_2 - \mu' (\mu'_0 W)] + \mu' f'_0 \]  

(12)

\( \rho \) —— Air density under proposed correction conditions;  
\( \rho_0 \) —— Air density at 0m altitude and 20°C.

According to formula (10) and formula (12), the corrected vehicle coasting resistance coefficients \( f_0 \) and \( f_2 \) are obtained, and then the corrected vehicle coasting resistance is calculated according to the following formula.

\[ F_{corrected} = f'_0 + f'_2 V^2 \]  

(13)

### 3 Experimental setup and method

#### 3.1 Experiment method

In order to verify the correctness of the above coasting resistance correction method, three different types of vehicles (passenger car, SUV and pickup) were selected as the test vehicles. The road coasting tests were carried out at different altitudes (842, 1520, 2676 and 3554 meters) and four different temperatures from -15 °C to 25°C. The coasting test was carried out under the conditions of 0 meters and 20°C. The coasting resistance under this condition was corrected to other altitude and temperature conditions using the correction method in the text, and the actual coasting resistance was compared to verify the accuracy of the correction method. According to the requirements of GB18352.6-2016, the coasting test should meet the test conditions shown in Table 1.
The coasting test can be carried out, after the above conditions are met. The steps for measuring the coasting resistance corresponding to the vehicle speed V are as follows:

1) Accelerate the vehicle to above V+10km/h;
2) Put in neutral gear to allow the vehicle to coast freely, and use the instrument to record the corresponding coasting time t1 when the vehicle speed is reduced from V+ΔV km/h to V-ΔV km/h (ΔV=5km/h), and the corresponding coasting resistance f1=2×M×ΔV/3.6/t1;
3) Perform the same test in the opposite direction and measure t2, the corresponding coasting resistance f2=2×M×ΔV/3.6/t2, the average value Fi of f1 and f2 can be obtained;
4) Repeat the above process n times to get the average resistance F=(F1+F2+…+Fn)/n corresponding to the vehicle speed V;
5) During each test, taxi the vehicle from 130km/h to 10km/h, and calculate the actual coasting resistance corresponding to the vehicle speed from 120km/h to 20km/h every 10km/h;
6) Using formula (5) to formula (13), the theoretical corrected coasting resistance of vehicles at different altitudes and temperatures can be calculated;
7) Judge the correctness of the coasting resistance correction method by comparing the actual coasting resistance with the theoretical correction coasting resistance.

### 3.2 Experiment equipment

The accurate measurement of test environment parameters, vehicle status and test data is a prerequisite to ensure correct test results. A variety of high-precision test equipment is used to collect different test data as shown in Table 2.

When the test site meets the test conditions in Table 1, all instruments are in normal working conditions, the vehicle is preheated, and the information such as tire pressure, oil temperature and coolant temperature are monitored in real time to ensure these parameters the same before each test. When the requirements are met, the vehicle can be tested in forward and reverse directions, and at least 6 sets of forward and reverse tests can be completed to reduce the test error.

### Table 1. Coasting test conditions.

<table>
<thead>
<tr>
<th>Road conditions</th>
<th>Atmospheric conditions</th>
<th>Vehicle status</th>
</tr>
</thead>
<tbody>
<tr>
<td>The road is straight and dry;</td>
<td>The average wind speed is less than 3m/s;</td>
<td>The vehicle is operating normally;</td>
</tr>
<tr>
<td>The slope is less than 1.5%;</td>
<td>The maximum wind speed is less than 5m/s;</td>
<td>The operating temperature is normal before the test;</td>
</tr>
<tr>
<td>The slope change is less than ±0.1%</td>
<td>The lateral wind speed is less than 2m/s;</td>
<td>The tire pressure is normal;</td>
</tr>
<tr>
<td></td>
<td></td>
<td>The windows and air conditioners of the vehicle are closed</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>experiment equipment</th>
<th>purpose</th>
</tr>
</thead>
<tbody>
<tr>
<td>Altimeter</td>
<td>Measuring altitude and slope road</td>
</tr>
<tr>
<td>Portable weather station</td>
<td>Measuring air pressure, temperature and humidity, wind speed and light</td>
</tr>
<tr>
<td>Handheld weather meter</td>
<td>Measurement of the air density</td>
</tr>
<tr>
<td>Tire pressure monitor</td>
<td>Measuring tire pressure and temperature</td>
</tr>
<tr>
<td>OBD diagnostic instrument</td>
<td>Reading vehicle data such as oil temperature, coolant temperature and vehicle speed through the OBD interface</td>
</tr>
<tr>
<td>Vehicle road speedometer</td>
<td>Measure information such as vehicle speed, running time and distance</td>
</tr>
</tbody>
</table>
4 Analysis of test results

4.1 Analysis of the passenger car's coasting results

In order to ensure the accuracy of the test results, the car must meet the following vehicle conditions before each test: the oil temperature and coolant temperature reach 90 ± 5°C, and the tire pressure is 2.5bar when the tire is cold. The results of the measured coasting resistance and the corrected coasting resistance of the car under various conditions are shown in Figures 1 to 4. In order to make the graphics clearer, only the coasting data at two temperatures are shown in the figure.

**Fig. 1.** Coasting results at an altitude of 840 meters.

**Fig. 2.** Coasting results at an altitude of 1520 meters.

**Fig. 3.** Coasting results at an altitude of 2676 meters.
4 Analysis of test results

4.1 Analysis of the passenger car's coasting results

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Fig. 1. Coasting results at an altitude of 840 meters.
Fig. 2. Coasting results at an altitude of 1520 meters.
Fig. 3. Coasting results at an altitude of 2676 meters.
Fig. 4. Coasting results at an altitude of 3554 meters.

As can be seen from above figure, the measured coasting resistance and the corrected coasting resistance of the car under different conditions are in good agreement, and the error between the two is basically maintained within 3%. Only at individual low-speed test points, there is a large error, but it is also within 6%. This is mainly because when the vehicle speed is low, the coasting resistance of the vehicle is small, and the slight fluctuation of the test environment conditions (especially the wind speed) will cause a large error.

4.2 Analysis of the SUV's coasting results

The coasting test was carried out on the vehicle under different test altitude and temperature conditions. The correction value, measured value and error of the taxiing resistance are shown in Figure 5 to Figure 8.

Fig. 5. Coasing results at an altitude of 840 meters.
Fig. 6. Coasing results at an altitude of 1520 meters.
Fig. 7. Coasing results at an altitude of 2676 meters.
Fig. 8. Coasing results at an altitude of 3554 meters.
The results of the SUV taxi test are similar to those of the car. It can be seen from the figure that the taxi resistance correction method given in the article can accurately correct the taxi resistance of the vehicle to various altitudes and temperature conditions, with an error within 4%. The maximum error at different vehicle speeds is below 6%.

4.3 Analysis of the pickup's coasting results

In order to ensure the accuracy of the taxiing test results, the pickup truck must meet the following vehicle conditions before each test: the oil temperature and coolant temperature reach 90 ± 5°C; when the tires are cold, the tire pressure is 2.4bar.
The results of the SUV taxi test are similar to those of the car. It can be seen from the figure that the taxi resistance correction method given in the article can accurately correct the taxi resistance of the vehicle to various altitudes and temperature conditions, with an error within 4%. The maximum error at different vehicle speeds is below 6%.

4.3 Analysis of the pickup's coasting results

In order to ensure the accuracy of the taxiing test results, the pickup truck must meet the following vehicle conditions before each test: the oil temperature and coolant temperature reach 90 ± 5 ℃; when the tires are cold, the tire pressure is 2.4 bar.

Similarly, the coasting resistance correction method for pickup trucks can also achieve a good correction effect. The error between the correction result and the actual measurement result is mostly below 4%. In some cases, the correction error is relatively large, but it is also within 6%. This situation is mainly when it appears at a higher altitude, the natural conditions (wind speed) are prone to change during the test, resulting in larger test errors.

5 Conclusion

In order to solve the problem of vehicle coasting resistance at high altitude, three different types of vehicles, passenger car, SUV, and Pickup, are selected to conduct altitude coasting resistance research. The test conclusions are as follows:
1) The coasting resistance correction method in SAE J1263 establishes the coasting resistance equation based on automobile theory, which mainly consists of rolling resistance and air resistance, and indicates that altitude (mainly affecting air density), temperature and wind speed are the main influences of vehicle coasting resistance factors. In this paper, temperature and wind speed are used to correct rolling resistance, and air density is used to correct air resistance.

2) For different types of vehicles, the coasting resistance correction method can accurately realize the correction of the coasting resistance. In most cases, the error is within 4%, and in some cases, it can reach 6%.

3) Using this correction method, the tester only needs to obtain the coasting resistance of the vehicle under the conditions of 0 meters and 20°C, and then can calculate the coasting resistance of the vehicle under different altitude and temperature conditions, which greatly saves the time and cost of the test.

Reference

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