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Dynamic performance of a pure electric vehicle experimental analysis

WANG Tan-li[1, a], CHEN Chang-hong[1, b], GAO Shi-zhan[1, c],LI Xing-quan[1, d] and YU Ying-xiao[1, e]

College of Automobile and Transportation Engineering, Liaoning University of Technology, Jinzhou 121001, China

[a] WTL57@163.com, [b]ccs005@126.com,[c]443261350@qq.com, [d]lixingquan_2004@126.com, [e]87485286@qq.com

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Abstract. On the basis of analysis of the slop and accelerate inertia force affect on the driving force, this paper propose a calculate method of the maximum driving force and gradient based on the acceleration of the flat road and slop. The result show that the proposed calculate method of electric vehicle maximum gradient can effectively evaluate the climbing performance.

Introduction

The dynamic performance of electric vehicles has the same evaluation standard with traditional fuel vehicles, the maximum speed, acceleration time and the maximum climbable gradient. Electric vehicle's drive motor should have a restricted overload ability. The overload ability is closely related to the electric vehicle's acceleration ability and the largest climbing gradient [1] [2]. When manufacture do the experiment of the electric vehicle, it is difficult to find a suitable gradient to evaluate the climbable performance of electric vehicles, so <experiment method of the dynamic performance of a electric vehicle>(GB / T 18385-2005) use the method of loaded mass to evaluate the maximum climbing gradient. This approach for the realization of micro-electric vehicle is very difficult. That is because the mass is often loaded far beyond the vehicle's affordability, and it makes the car's axle load transference becomes complex. So it is not conducive to the analysis of the vehicle dynamic.

The research object is a pure electric vehicle. Analysis the influence of slop gradient, acceleration inertia and ground adhesion coefficient. Then propose a calculate method of maximum climbing gradient. By the processing the dynamic performance data, it can get the maximum driving force at the tire ground center. Considering of the restrictions of the slope axle load transference and the road adhesion force, use the maximum driving force to calculate the climbing ability.

The influence of working condition on adhesion force of the driving wheel

Slop influence on adhesion force. The stress situation of the front wheel driving vehicle in the condition of climbing slop is shown in Fig.1

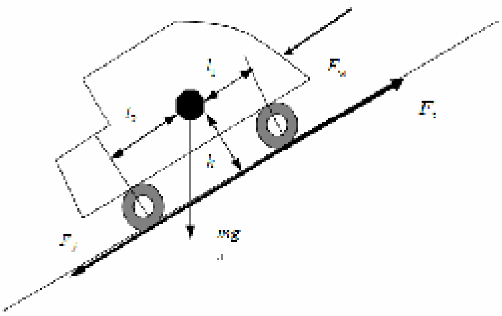

Fig.1 Stress Analyze of EV

When the vehicle is climbing, vehicle is working at a low and uniform speed. Air resistance, air lift and accelerate resistance has little effect on ground reaction forces. So it can be neglected. Front and rear axle ground reactions in normal direction are given by (1) [3] :

$$F_{z1}=\frac{mg(l_2\cos a-h\sin a)}{l},\quad F_{z2}=\frac{mg(l_1\cos a+h\sin a)}{l} \qquad (1)$$

where:FZ1,FZ2—front and rear axle ground reaction force in normal direction (N);

l1,l2—the distance from front and rear axles to the center of mass (m);

l—wheelbase(m);

α—slop angle(°);

m—vehicle quality(kg);

h—height of the center of mass(m)

Therefore, the front and rear axle normal ground reaction force changes with the slope angle. The slop makes the axle-load transfer. Then the ground reaction force changes. So it causes changes of the adhesion force of the driving wheel. It is shown in (2).

$$F_u=F_{z1}u=\frac{mg(l_2\cos a-h\sin a)}{l}u \qquad (2)$$

Where: u-ground adhesion coefficient.

In the dry asphalt road, take the adhesion coefficient u= 0.8, from expression (1), (2) can obtain the relation between normal ground reaction force, adhesion force and the slope angle. It is shown in Figure 2.

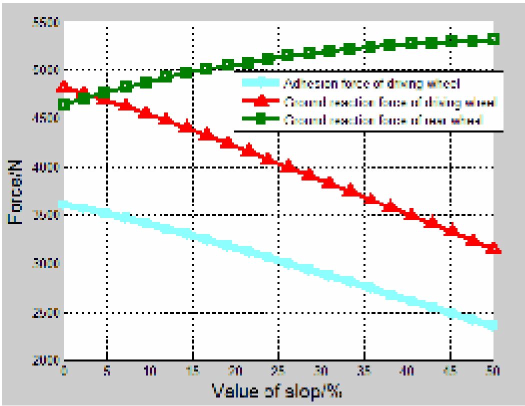

Fig.2 slope influence on adhesion

It can be seen in (2) and Fig.2, if the vehicle structural parameter doesn't change, front wheel adhesion force will decrease with the increase of the slop gradient. The limitation of climbing ability is the driving force and the ground adhesion. When the driving force is bigger than adhesion force, the driving force of the wheels will not increase.

The acceleration inertia force influence on adhesion force. When the vehicle is climbing the slop, the rear and front ground reaction force is under the influence on slop and inertia force. The reaction force is shown in expression (3),(4):

$$F_{z1}=\frac{mg(l_2\cos a-h\sin a)}{l}-m\frac{h}{l}\frac{dv}{dt} \qquad (3)$$

$$F_{z2}=\frac{mg(l_1\cos a+h\sin a)}{l}+m\frac{h}{l}\frac{dv}{dt} \qquad (4)$$

Adhesion force of the driving wheel is shown in Fig.5:

$$F_u=[\frac{mg(l_2\cos a-h\sin a)}{l}-m\frac{h}{l}\frac{dv}{dt}]u$$

(5)

From expression (3), (4), (5), it can obtain the reaction force and adhesion force, when the vehicle is climbing slop. It is shown in Fig.3

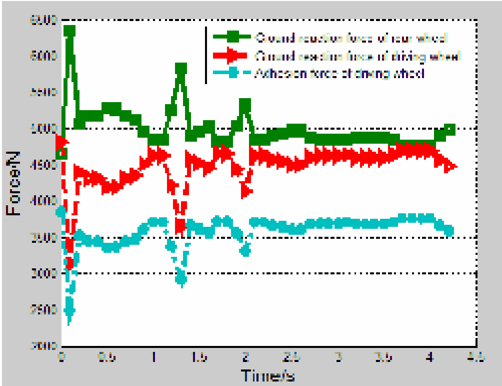

Fig.3 acceleration influence on adhesion force

It can be seen in Fig.3, under the influence of acceleration inertia on slop, the front and rear reaction force is changes. Therefore, when the vehicle accelerates on the slop, should consider of whether the adhesion force limit the driving force.

Calculation method of the maximum climbing gradient

As shown above, the experiment is limited by the experimental conditions and practical constraints. When we do dynamic experiment, it is difficult to find a slop which can match the maximum gradient. One solution is using the method of changing load mass. It is shown in expression (6)

$$\Delta m = m \times \frac{(\sin a_0 - \sin a_1)}{(\sin a_1 + f)} \tag{6}$$

Where: Δm— changes of the load mass (kg);

a_1 —experimental slope angle (°);

a_0 — prescribed maximum climbing gradient (°);

f — rolling resistance coefficient.

This method is not feasible for most of the mini-vehicle test. For example, we choose the electric vehicle mentioned on this article to use the method. If we want to change the gradient from 12% to 30%, we will need to load the mass of about 1500kg. The load process will be tedious. And it will be far beyond the affordability of the car.

During the accelerating climbing tests, the driving motor output peak power. In the acceleration test, press the accelerator electronic pedal to the maximum, the power is totally used to overcome resistance force to accelerate or climb slop. At this time, the actual maximum driving force from type can make the vehicle to reach the, maximum gradient. That gradient is the maximum gradient.

Then analyse the result of the acceleration on flat road or slop. According to the acceleration capacity and ground adhesion limit, we can get the motor driving force. That is the actual maximum driving force. Use this force to calculate the maximum climbing gradient.

When the vehicle is accelerating, the maximum driving force from type is Ftmax. Using this force to climb the maximum climbing gradient, we get the resistance force. It is shown in expression (7).

$$F_{t\max} = mgf \cos a_{\max} + mg \sin a_{\max} \tag{7}$$

According to expression (7) can obtain the maximum climbing gradient $a_{\max}$. It is shown in expression (8).

$$a_{\max} = \arcsin \frac{F_{t\max}/G - f\sqrt{1-(F_{t\max}/G)^2 + f^2}}{1+f^2} \tag{8}$$

Where: G=mg.

According to 1.1, the actual climbing gradient is under the influence of driving force and ground adhesion force. In the limit condition, driving force equal to the adhesion force. Due to the shaft load transfer, the rolling resistance force will change. The front wheel slippage rolling resistance is 0. At this time, the rear wheel rolling resistance is shown in expression (9).

$$F_f = mgf\left(\frac{l_1}{l}\cos a + \frac{h}{l}\sin a\right) \tag{9}$$

The driving force means adhesion force equal to resistance force, which is needed to overcome.

$$F_u = F_f + mg \sin a \tag{10}$$

From expression (2) and (11), we can get the maximum climbing gradient, in the condition of the limit adhesion force.

$$i_2 = \tan a = \frac{l_2 u - l_1 f}{l + (f + u)h} \tag{11}$$

When the vehicle is climbing slop, the axle load transfer makes the driving wheel reaction force change. It may cause the adhesion force reduce. Therefore, restriction of the actual driving force limits the climbing capacity. From the obtained i1, i2, the minimum value is the actual maximum climbing ability.

Analysis the vehicle experiment, obtain the maximum driving force

Lexperiment condition. The parameters of electric vehicle are shown in Table 1.

Table 1 Parameters of electric vehicle

Parameters of electric vehicle	
experimental vehicle mass kg	966
size mm	2558×1450×1597
Wheelbase mm	1800
distance from Front axle to centroid mm	884
centroid height mm	530
transmission ratio	13
rated power of the motor kw	5.5
maximum rotational speed r/min	5500

According to the standard of <experiment method of the dynamic performance of a electric vehicle>(GB/T18385-2005), we use the CTM810 integrated tester to test the vehicle dynamic performance. The experimental content includes acceleration in flat road and slop. The sampling internal is 0.28m/s.

The process of experiment. Process the experiment data to get the actual driving force. The process is shown in Fig.4.

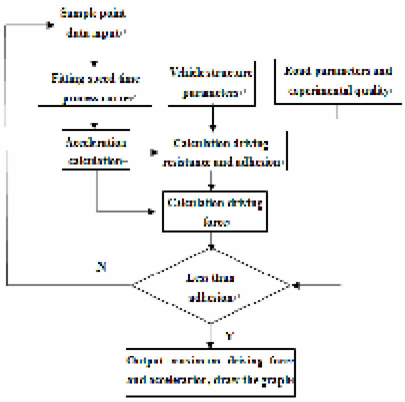

Fig.4 flow chart of experiment data processing

It can be seen in Fig.4, firstly, input the sampling data. Then use the speed of sampling points to fit a curve. According to the speed, sample interval and the system step length, calculate the acceleration. According to the parameters of vehicle and the road situation, calculate the adhesion force and driving force. If the adhesion force limits the driving force, it will input the next series of data. If the adhesion force doesn't limit the driving force, it will draw the diagram. According to the diagram, we can obtain the maximum acceleration driving force.

Analyze of the experiment data

The acceleration performance on flat road. According to the result of experiment data processing, vehicle's acceleration performance and driving fore changes is shown in Fig. 5 and Fig. 6. It can be seen in 0-3s, the driving force and acceleration fluctuates considerably. The maximum current of the motor controller is 530A-550A. The fluctuation is very fast. So the output torque of the driving motor is unstable. During the acceleration process, the speed from 30km/h to the maximum, the motor controller's current change from 50A to 60A gradually. At this time, the current become steady gradually. The driving force and the acceleration reduce to steady value gradually. From Fig.6, we can obtain the actual maximum driving force in short a time.

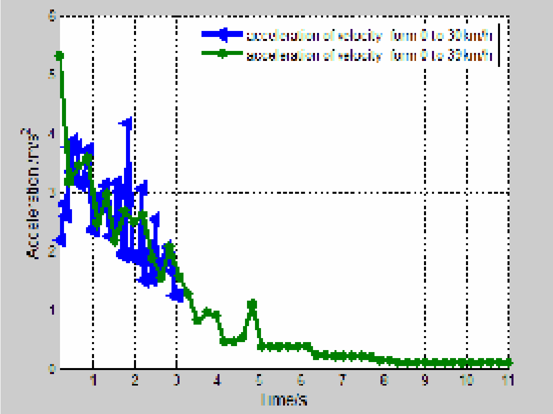

Fig.5 The change of acceleration

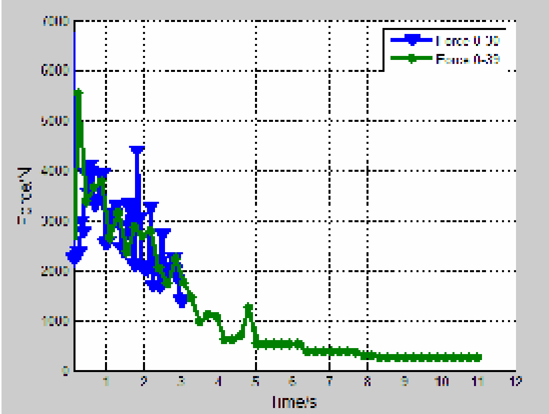

Fig.6 The change of the driving force in the tires

Analyze of the climbing acceleration performance. In the climbing acceleration experiment, the speed changes from 10km/h to 30km/h. Acceleration and driving force of climbing acceleration are shown in Fig. 7 and Fig. 8. Under the influence of slop and acceleration inertia force, sometimes, the adhesion force limits the driving force. Therefore, the actual driving force exceeds or equal to the driving force in Fig.7 and Fig.8.

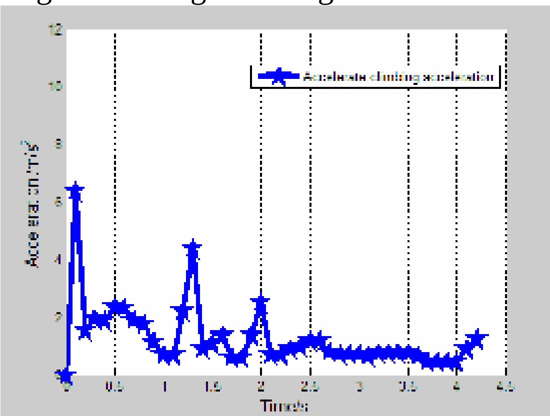

Fig.7 The change of acceleration

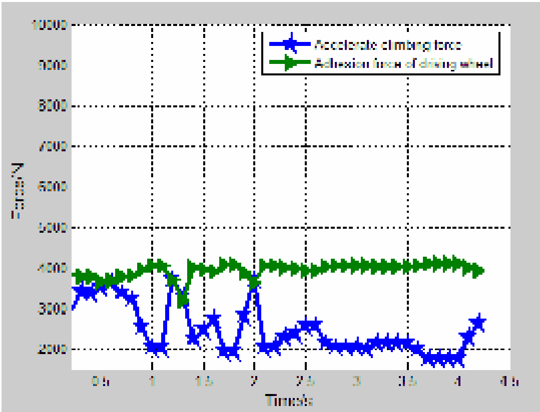

Fig.8 The change of the tires driving force

The calculation of the maximum climbing gradient. It can be seen in the Fig. 6 and Fig. 8, the actual text electric vehicle's driving force is above 3000N. So this paper chooses the tires ground average driving force of 3000N. Calculated with the formula (8), can obtain the maximum climbing gradient: $i_1 = 28.1\%$. From expression (12), we can obtain the maximum gradient $i_2 = 35.9\%$ by the limit of ground adhesion force. So this electric vehicle can reach the climbing gradient of 28.1%.

Conclusions

This paper doesn't consider of the constraint of loss steering. A pure electric vehicle as the research object, analysis the slop and acceleration inertia force influence on the front and rear ground reaction force. This paper proposes an acceleration experiment method of micro-electric vehicle. So it provides a new mean to experiment and calculate the micro-electric vehicle's maximum climbing gradient.

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