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Study on Improvement of Climbing Ability of Multi-Motor Driven Vehicle

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Abstract. In this paper, the force analysis of the driving axle and the whole of the vehicle is carried out. By analyzing and comparing the relationship between the driving force provided by the motor, the load force of the driving axle before and after the vehicle, and the resistance of the vehicle's climbing slope, the influence of the uneven distribution of the driving axle load before and after the vehicle on the maximum climbing gradient of the vehicle is discussed.The method of balancing the driving axle load before and after by changing the relative position of the center of mass in a multi-drive electric vehicle with a certain motor power is proposed.On this basis, the feasibility of changing the relative centroid position of the vehicle to improve the maximum climbing gradient is verified by an example calculation, which provides a reference for the calculation of vehicle modification.

1. Introductions

With the increasing pressure of energy crisis and environment, electric vehicle has become an important direction of the development of vehicle industry in various countries. In the military field, the theory of unmanned combat is becoming mature. Electric vehicles, especially independent motor driven vehicles, due to the drive and brake torque of the driving motor can be controlled independently, each other, can greatly improve the electric vehicle power performance, stability, security and other advantages, making military special vehicles in the design and modification has the new breakthrough. It provides a technical approach to realize the theory of unmanned combat. However, multi-drive not only solves certain problems, but also puts forward new problems, that is, higher requirements for motor drive control are put forward.

Electric driving vehicles require good performance in passing and dynamic performance, among which the maximum gradient is the most intuitive evaluation index of these two indicators.When the vehicle climbs a slope driven by electricity, due to the influence of factors such as slope, center of mass position, speed, acceleration, etc., the load distribution of the front and rear wheels of the vehicle is not uniform. The load distribution is uneven, which leads to the different adhesion force that the front and rear wheels can provide, and thus affects the climbing ability of the vehicle. This effect can be solved by differential lock in single-drive vehicles, but it cannot be solved by differential lock in multi-drive vehicles. [1]

In order to solve this problem, this paper takes the multi-driven XXX modified vehicle as the object of analysis. By discussing the impact of the relative position of the vehicle's center of mass on the front and rear wheel loads, it tries to solve the adverse effect of the uneven distribution of vehicle loads on the maximum gradient of multi-driven vehicles. [2]

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2. Force analysis of driving wheel and vehicle

2.1. Force analysis of driving wheel

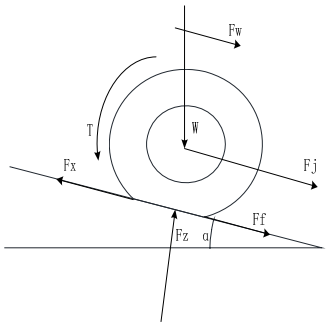


Fig 1. Driving wheel stress analysis diagram

When the vehicle is running, the force of its driving wheel is shown in the figure.
Do the force balance equation:

$$F_x = F_f + F_i + F_j + F_w \tag{1}$$

In the formula, F_x is the reaction force given by the ground when the vehicle is moving.When the tire and vehicle have enough adhesion, the driving force F_x is equal to F_t that of the motor acting on the driving wheel through the driving shaft.The calculation formula is:

$$F_x = F_t = \frac{M_e \cdot i \cdot \eta}{r} \tag{2}$$

F_f is the rolling resistance in the process of running, which is caused by the friction coefficient between the vehicle and the ground [3].The calculation formula is: $F_f = G \cdot \cos\alpha \cdot f$; F_i is the ramp resistance of the vehicle in the process of climbing, and its calculation formula is: $F_i = G \cdot \sin\alpha$; F_j is acceleration resistance, which is due to acceleration due to the inertial force a .The calculation formula is: $F_j = \frac{\delta G}{g}\frac{dv}{dt}$; F_w is air resistance, and its calculation formula is: $F_w = \frac{C_D A v_a^2}{21.15}$.

Among them, the acceleration resistance of the vehicle F_j can be neglected because it does not require much for acceleration performance when climbing the slope.In addition, in order to guarantee the stability and safety of the vehicle, the vehicle speed is generally low, so the air resistance of the vehicle F_w will be small and negligible.In the case that both acceleration resistance F_j and air resistance F_w are neglected, equation (1) can be simplified as:

$$F_x = F_t = F_f + F_i = G \cdot \cos\alpha \cdot f + G \cdot \sin\alpha \tag{3}$$

The force analysis of the whole vehicle is derived from equation (3).

2.2. Overall force analysis of vehicles

In the force analysis of 2.1 driving wheels, the acceleration resistance F_j and air resistance F_w are ignored through comparison.On this basis, the overall stress analysis chart of the vehicle is shown in figure 2

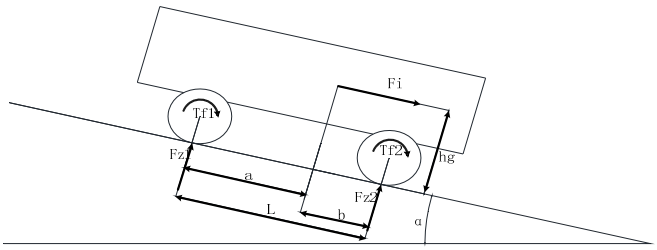


Fig 2. Overall stress analysis diagram of the vehicle

In the figure, a is the distance between the driving axle center of the front drive axle and the center of mass, b is the horizontal distance between the driving axle center of the rear drive axle and the center of mass, h_g and is the vertical distance between the vehicle's center of mass and the ramp.

In order to obtain the bearing capacity of vehicle's front F_{z1} and rear wheels F_{z2}, the balance equation of moment of center row of contact surface between vehicle's front and rear wheels and the ground respectively [4].

Firstly, the bearing capacity of vehicle front wheel F_{z1} is solved by solving the moment balance equation of vehicle rear wheel and ground contact center row:

$$G\cos\alpha \cdot b - Gh_g \sin\alpha - \sum T_f - F_{z1}L = 0 \tag{4}$$

Where, substitute it into equation (4): $\sum T_f = G\cos\alpha \cdot f \cdot r$

$$G\cos\alpha \cdot (b - fr) - Gh_g \sin\alpha - F_{z1}L = 0 \tag{5}$$

The bearing capacity of the front wheel of the vehicle F_{z1} obtained from equation (5) is:

$$F_{z1} = \frac{G\cos\alpha \cdot (b - fr) - Gh_g \sin\alpha}{L} \tag{6}$$

Similarly, for solving the torque balance equation of vehicle front wheel and ground contact center row, the bearing capacity of vehicle front wheel F_{z2} is:

$$F_{z2} = \frac{G\cos\alpha \cdot (a + fr) + Gh_g \sin\alpha}{L} \tag{7}$$

On a good road surface, the friction coefficient of the ground f is small, so it can be considered that, $b - fr \approx b$, $a + fr \approx a$ .After simplification, the bearing capacity of the front and rear wheels can be expressed as:

$$\begin{cases} F_{z1} = \dfrac{G \times b \times \cos\alpha}{L} - \dfrac{h_g}{L} G \sin\alpha \\ \\ F_{z2} = \dfrac{G \times a \times \cos\alpha}{L} + \dfrac{h_g}{L} G \sin\alpha \end{cases} \tag{8}$$

The former term $\dfrac{Gb\cos\alpha}{L}$ and $\dfrac{Ga\cos\alpha}{L}$ is the static load on the front and rear axle when the car is stationary horizontally.It is mainly determined by the position of the center of mass. The closer the center of mass is to the front drive shaft, the greater the static load of the front drive shaft and vice versa. The remaining part is the dynamic load in the driving process, which increases with the increase of slope, speed and acceleration [5].

3. Specific parameters of multi-drive XXX modified vehicle

3.1. Quality parameters

Vehicle quality: m 2,600 kg

Gravity: G 25480 N

3.2. Car body parameters

Driving shaft wheelbase: L 6.642 m

Height of center of mass: h_g 0.74 m

Horizontal distance from front drive shaft to center of mass: a 4.994 m

Horizontal distance from rear drive shaft to center of mass: b 1.648 m

Wheel diameter: D 712 mm

3.3. Motor parameters (one drive is powered by two motors working together)

Peak torque of single motor: M_e 110 $N \cdot m$

Deceleration ratio: i 20

Maximum speed: $1000 r / \min$

Output peak torque: 2200 $N \cdot m$

3.4. Other parameters

Referring to relevant reference materials, the transmission efficiency is 0.83. η The road adhesion coefficient was 0.7, and the road rolling resistance coefficient was 0.15. φ f

4. Discuss the influence of the center of mass position on maximum climbing gradient

4.1. Comparison and analysis of vehicle four forces

In the process of vehicle climbing, the most important is the relationship between adhesion force F_{φ}, driving force F_t, slope resistance F_i and rolling resistance F_f .For the multi-driven XXX vehicle, the force is calculated through MATLAB, and the figure is as follows:

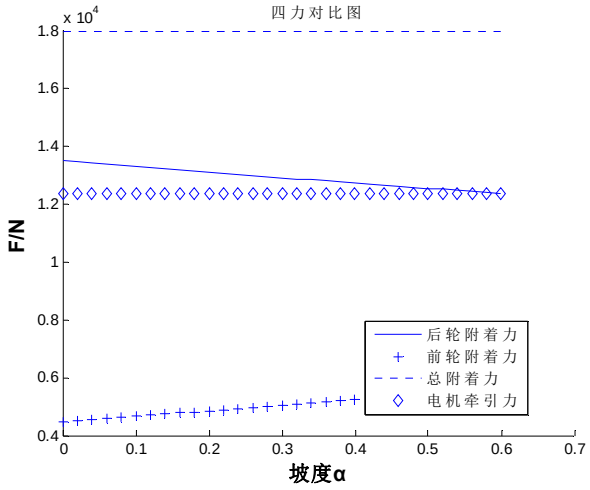


Fig 3. Comparison of four forces

It can be clearly seen from the figure:

(1) With the increase of gradient, the bearing capacity of the front drive bearing gradually decreases, and the bearing capacity of the rear drive shaft gradually increases. α However, there is still a large gap between the front drive shaft and the rear drive shaft due to the relation of center of mass.

(2) Under the condition that the selected motor works normally, the traction force provided by the motor is less than the required adhesion of the vehicle's front drive shaft, that is, it cannot provide sufficient adhesion; And far greater than the required adhesion of the rear drive shaft. As a result, the actual adhesion of the vehicle is not equal to the theoretical sum of the adhesion of the front drive shaft and the driving force of the rear drive shaft.

4.2. Change the position of relative center of mass

4.2.1. Theoretical analysis of the influence of the location of the center of mass. In order to solve the situation that the adhesion force of vehicles in the analysis conclusion in 4.1 cannot reach the theoretical adhesion value. In this paper, the uneven distribution of load of driving bearing before and after the vehicle is improved. That is to balance the current rear drive shaft when climbing the load. Equation (8)

$$\begin{cases} F_{z1} = \dfrac{G \times b \times \cos\alpha}{L} - \dfrac{h_g}{L} G \sin\alpha \\ F_{z2} = \dfrac{G \times a \times \cos\alpha}{L} + \dfrac{h_g}{L} G \sin\alpha \end{cases}$$

Order, $F_{z1} = F_{z2}$

$$\frac{G \times b \times \cos\alpha}{L} - \frac{h_g}{L} G \sin\alpha = \frac{G \times a \times \cos\alpha}{L} + \frac{h_g}{L} G \sin\alpha \tag{9}$$

Solution:

$$b - a = 2 \times h_g \times \tan\alpha \tag{10}$$

Which,

a -- the horizontal distance from the front drive shaft to the center of mass

b -- the horizontal distance from the driving shaft to the center of mass

h_g -- height of center of mass

α -- the slope of the ramp

Let $L_w = 2 \times h_g \times \tan\alpha$, that is the difference between the horizontal distance between the front and rear drive axes and the center of mass when the load distribution of the front and rear drive wheels is balanced at the slope α.

It can be obtained from equation (10) that the horizontal distance and difference between the front a and rear driving axes b and the center of mass should be a function of the height of the center of mass h_g and the slope of the ramp α .if the vehicle wants to make the load of driving wheels before and after climbing the slope consistent.It means that when the gradient α is certain, the relative position of the vehicle's center of mass can be changed to reduce or even eliminate the influence of the uneven distribution of load on the vehicle's front and rear drive axles on the maximum climbing gradient.

4.2.2. Methods to change the center of mass position in actual conditions. For the method of changing the relative centroid position of the vehicle, a method of changing only the horizontal position of the vehicle tire is proposed here, that is, by installing a sliding track on the vehicle's driving shaft, it can move forward and backward along the horizontal direction of the vehicle body. The specific performance is as follows:

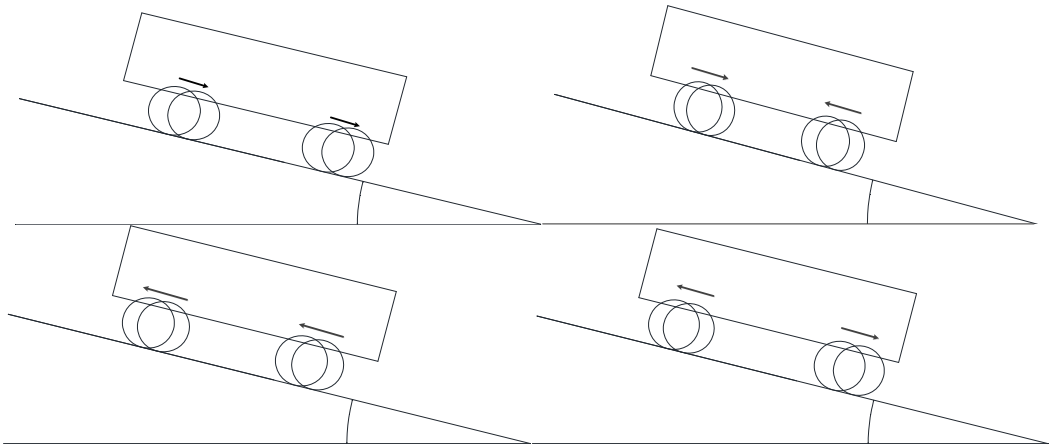


Fig 4. The method to change the center of mass

It can be clearly seen from figure 4 that the horizontal distance between the front a and rear drive axes b and the center of mass can be changed by the movement of the front and rear wheels.Therefore,

the problem of uneven distribution of driving shaft loads before and after can be improved and the maximum climbing gradient of vehicles can be improved.

However, it is impossible to predict the slope of the slope in advance in the actual climbing operation of the vehicle, so the distance between the driving axle before and after the vehicle cannot be adjusted to the appropriate position before the vehicle climbs the slope. To solve this problem, the following methods can be adopted. As the vehicle can perceive the slope of the slope α through the sensor in the process of climbing the slope α, the optimal difference between the front and rear driving shaft and the horizontal distance from the center of mass L_w can be calculated according to equation (10) when the slope of climbing α is known.The difference between L_w and the driving shaft and the center of mass $b-a$ is compared with the actual situation.Make the distance between the front and rear drive axles $b-a$ as close as possible to L_w through one (or several) of the four operations in figure 4, so as to achieve the purpose of increasing the maximum vehicle climbing gradient.

5. Numerical example

Taking the multi-drive XXX modified vehicle as an example, the effect of the balance front and rear wheel load on the maximum climbing gradient of the vehicle is verified, even if it is different from that of the balance front and rear driving wheels under normal conditions.

With gradability is 34 °slope as an example. By verifying the vehicle can climb to the top of slope is 34 °slope to explore the influence of the change of centroid position of vehicle maximum gradability.

5.1. The climbing ability of XXX modified vehicles under normal conditions

5.1.1. Motor output traction

$$F_q = \frac{M_e \times i \times \eta}{r}$$

Calculation: $F_q = 5129N$

Since one of the drive shafts of the XXX modified vehicle F_t is operated jointly by two motors. Therefore, the pull force on a single drive shaft shall be the output pull force of a single motor F_q multiplied by the number of motors n, namely:

$$F_t = F_q \times n$$

Calculation: $F_t = 10258N$

5.1.2. Resistance to climb. According to equation (3), the resistance to be overcome for slope climbing is F_x:

$$F_x = F_f + F_i = G \cdot \cos\alpha \cdot f + G \cdot \sin\alpha$$

Calculated: $F_x = 14538N$

XXX refitted vehicle to climb to the top of slope of 34 degrees, have to overcome the resistance of 14538N, means that the vehicle's engine should provide at least 14538N force.

5.1.3. Actual power provided by vehicle engines. According to the analysis in 4.2.1, the loading force of the vehicle's front and rear drive axles is calculated by equation (8).

$$\begin{cases} F_{z1} = \dfrac{G \times b \times \cos\alpha}{L} - \dfrac{h_g}{L} G \sin\alpha \\ F_{z2} = \dfrac{G \times a \times \cos\alpha}{L} + \dfrac{h_g}{L} G \sin\alpha \end{cases}$$

Calculated :

$$\begin{cases} F_{z1} = 3656N \\ F_{z2} = 17472N \end{cases}$$

The adhesion force can be obtained by multiplying the load capacity by the coefficient of adhesion φ.

$$\begin{cases} F_{\varphi 1} = 2559N \\ F_{\varphi 2} = 12230N \end{cases}$$

The adhesion force of the front and rear drive shafts is compared with that provided by the motor.

The adhesion force of the front wheel is smaller than the driving force provided by the motor, so the motor acting on the front wheel can output the driving force $F_{\varphi 1} = 2559N$. The adhesion force of the rear wheel is greater than that provided by the motor, so the motor acting on the rear wheel can only output the driving force which is equal to the $F_t = 10258N$ .As a result, the driving forceprovided by the engine of XXX modified vehicle in ordinary conditions F_{qu} is:

$$F_{qu} = F_{\varphi 1} + F_t$$

Calculated: $F_{qu} = 12817N$

By comparing the driving force F_{qu} with the resistance to be overcome in climbing F_x, the following results are obtained:

$$F_{qu} = 12817N < F_x = 14538N$$

So, in normal state, converted XXX can't climb up the slope to 34 ° slope.

5.2. The climbing ability of XXX modified vehicle after adjusting the center of mass

5.2.1. Adjust the relative position of the center of mass. According to the $b - a = 2 \times h_g \times \tan\alpha$
The optimum difference between the front and rear driving axes and the horizontal distance to the center of mass can be calculated $L_w = 1m$ on the premise of slope $\alpha = 34°$.

After analysis, the difference between the horizontal distance from the front and rear drive axes to the center of mass ($L_w = 1m$) can be achieved by the operation shown in figure 4 (forward drive axis moving backward, and rear drive axis also moving backward).

5.2.2. Slope climbing ability of the adjusted vehicle. After adjusting the relative centroid position of the vehicle, the uneven distribution of loads on the front and rear drive axles was eliminated.

$$F_{z1} = F_{z2}$$

In addition, when the vehicle is climbing, the total load and the total gravity of the vehicle are:

$$F_z = G \times \cos\alpha$$

Therefore, the load force of the front and rear drive axles of the vehicle is:

$$F_{z1} = F_{z2} = 10564N$$

The adhesion force of the driving shaft before and after the vehicle is obtained by multiplying the adhesion coefficient:

$$F_{\varphi 1} = F_{\varphi 2} = 7395N$$

Compared with the driving force provided by the vehicle motor $F_t = 10258N$, it is found that the adhesion force of the front and rear driving shafts is smaller than that provided by the motor F_t . Therefore, the driving force of the motors acting on the front and rear wheels can be output, which is $F_{\varphi 1} = F_{\varphi 2} = 7395N$ .Thus, after adjusting the center of mass position of XXX modified vehicle, the driving force provided by its engine $F_{qu}{}'$ is:

$$F_{qu}{}' = F_{\varphi 1} + F_{\varphi 2}$$

Calculated: $F_{qu}{}' = 14790N$

At this time, $F_{qu} = 14790N > F_x = 14538N$

So XXX modified vehicle after adjustment after the centroid position, can climb to the top of slope is 34 °slope.

6. Conclusion

(1) based on the above analysis and calculation, it can be obtained that the maximum vehicle slope α is a function of the relative position (including L , a , b , and h_g) of the slope and the center of mass.In the case that the gradient α has been determined, the maximum climbing gradient of the vehicle can be improved by changing the relative position of the vehicle's center of mass [6].

(2) by comparing the XXX hot-rod adjustment before, during and after the mass center position of slope is 34 °slope overcome ability, can be obtained: by changing the relative position to balance the vehicle mass center of the drive shaft before and after loading force, so as to further enhance the vehicle's biggest gradability is a feasible method.

(3) In this paper, a method to change the relative position of the center of mass is proposed. Besides this method, the relative position of the center of mass can be changed in other ways, such as lifting the vehicle chassis to change the vertical distance between the center of mass and the ground h_g .Change the horizontal and vertical distance of the center of mass by using the deformation wheel.

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