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Study on Two-segment Electric-mechanical Composite Braking Strategy of Tracked Vehicle Hybrid Transmission System

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Abstract

In order to lighten abrasion of braking system of hybrid electric tracked vehicle, according to characteristic of hybrid electric transmission, electric-mechanical composite braking method was proposed. By means of analyzing performance of electric braking and mechanical braking and three-segment composite braking strategy, two-segment electric-mechanical composite braking strategy was put forward in this paper. Simulation results of Matlab/Simulink indicated that the two-segment electric-mechanical composite braking strategy might reduce the demand of mechanical braking force and was well applied.

Keywords: tracked vehicle, electric transmission, composite braking, braking strategy

1 Introduction

Tracked vehicle has big mass and inertia. When braking with high speed and big braking force, braking drum in traditional braking system is easy to be destroyed. In hybrid electric vehicle, power is transferred by electric and mechanical system. When braking, driving motor can work at braking state, which is electric braking. It combines with mechanical braking to implement composite braking.

Electric-mechanical composite braking is

always used in railway vehicle. With the development of hybrid electric vehicle, the braking system applying to hybrid electric vehicle is a hotspot on study gradually. This paper lists advantage and disadvantage of mechanical braking and electric braking respectively, an ideal three-segment electric-mechanical composite braking strategy and braking control targets. For a tracked vehicle, electric-mechanical composite braking model is established. By means of

simulation, performance of vehicle adopting three-segment electric-mechanical composite braking strategy can't achieve braking control targets. Under this condition, two-segment electric-mechanical composite braking strategy is put forward. Based on simulation analysis, the two-segment braking strategy can be better to meet braking request. The result of analysis provides theory gist for improving hybrid electric tracked vehicle.

2 Ideal braking strategy of composite braking and braking control targets

The advantages of electric braking are energy reclaim and rapid response. Well, the disadvantage is that with motor speed decreasing, electric current and braking torque decrease, when motor speed decreases to a certain degree, braking torque is decreasing to zero, the vehicle can't implement stand still. Mechanic braking can make up the disadvantage of electric braking in low speed, because efficiency of mechanical braking is steady in low speed. But in high speed, efficiency of mechanical braking decreases because of braking abrasion. Therefore, in the braking process, electric-mechanical composite braking makes the best of the advantage of electric braking and mechanical braking, which makes vehicle stop steadily and also protects mechanical braking.

The three-segment electric-mechanical composite braking strategy of reference [1] is that:

- 1) First segment: electric braking is adopted to reclaim energy at high speed;
- 2) Second segment: mechanical braking starts up when speed decreases to a certain degree. Together with electric braking, electric-mechanical composite braking advances braking efficiency;
- 3) Third segment: when velocity still

decreases, electric braking comes to low efficiency area, at this time, turning off electric braking, mechanical braking makes vehicle stand still solely.

The braking performance estimates of tracked vehicle are mainly as follows ^[2]: 1) braking distance; 2) braking time; 3) braking deceleration; 4) thermal load of braking.

Braking distance is relative to braking time and braking deceleration. Thermal load of braking is continual braking capability of braking, which is not calculated in this paper. Therefore, braking performance estimates in this paper are braking distance and braking time.

Braking of vehicle include parking braking process and decelerating braking process. While parking braking process includes decelerating braking process, so parking braking process is only analyzed in this paper. The maximum intensity of parking braking process is that velocity decelerates from a high speed to zero which is the analysis object in this paper. According to composite braking index of tracked vehicle hybrid transmission ^[3], optimal control target of composite braking is:

$$\left. \begin{array}{l} \max t \leq 4s \\ \max |a| \geq 5m / s^2 \end{array} \right\} \quad (1)$$

t is the time that speed braking from 65km/h to zero;

a is the deceleration that speed braking from 65km/h to zero.

3 Composite braking model of tracked vehicle

3.1. Vehicle model^[2]

For tracked vehicle, vehicle braking dynamics equations on horizontal road are:

$$F_f + F_B + F_w = \delta m \frac{du}{dt} \quad (2)$$

$$u|_{t=0} = u_0, \quad u|_{t=t_1} = 0 \quad (3)$$

In equation, F_f -rolling resistance force, F_B -braking force (mechanic braking force or electric braking force when mechanic braking or electric braking work solely), F_w - air resistance force, δ -mass increased coefficient, m -mass of vehicle, u_0 - initial velocity (here is 65km/h), t_1 -braking time.

During simulation, mass of vehicle is 7800kg, rolling resistance coefficient is 0.05 and mass increased coefficient is 1.2.

3.2. Electric braking system model

The electric transmission system in this paper is transverse axis structure. A big power permanent magnet synchronous motor is installed on main axle to output power. Braking in maximal energy condition can achieve best braking times. Electric braking modes are mainly about reverse-connection braking, energy-consumed braking and regenerative braking^[4]. In order to give full play to advantage of electric braking, the mode of combining regenerative braking and

energy-consumed braking is adopted according to the tracked vehicle in this paper, which is that when SOC of storage device is on low level, regenerative braking is on work, and when SOC is on high level, energy-consumed braking is on work, energy of braking is consumed by braking resistance in the form of heat.

The permanent magnet synchronous motor in motor drive system is controlled by controller. The torque-speed characteristic has ideal drive characteristic, which is constant torque characteristic under based-speed and constant power above based-speed. Some motor characteristic curve is shown in figure 1.

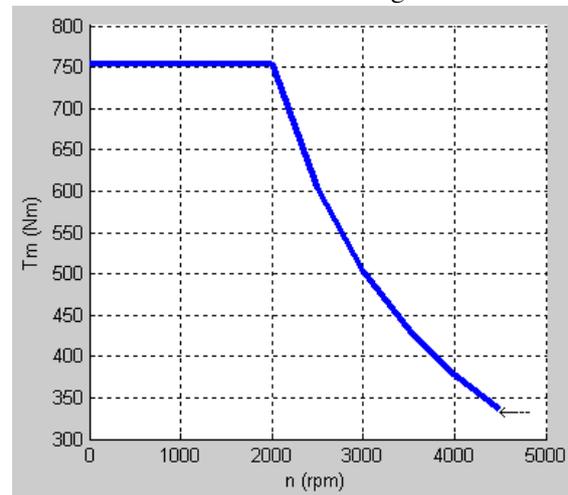


Figure 1: motor characteristic curve

3.3. Mechanical braking system model

When mechanical braking works solely, ground braking force firstly lied on braking force of braking, and at the same time is restricted by adhesion condition. Only when the braking has enough braking force and the ground has enough adhesion force can vehicle obtain enough ground braking force. In this paper, maximum braking force of braking is equal to adhesion force. During braking, mechanical braking force is smaller, the braking system is better.

$$F_{B,m\max} = \varphi mg \quad (4)$$

In equation (4), φ is adhesion coefficient, assumed that $\varphi = 0.4$; $F_{B,mmax}$ is the maximum braking force offered by mechanic

braking.

According to the analysis on the above, the simulation model based on Matlab/Simulink is showed as follows.

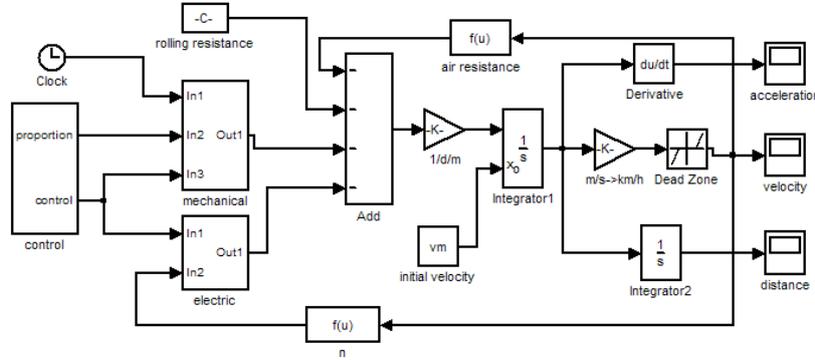


Figure 2: model of braking simulation

In the model above, the module 'control' is control part, control selection of mechanical braking or electric braking, or electric-mechanical composite braking, and mechanical braking force. The module 'proportion' represents output proportion of maximum mechanical braking force. The module 'mechanical' represents mechanical braking. The module 'electric' represents electric braking. The module 'clock' control the right time that mechanical braking is on work at.

4 Result of simulation and two-segment composite braking strategy

If the three-segment electric-mechanical composite braking strategy mentioned above is adopted, in order to achieve braking control targets, it is key to make sure the right time that mechanical braking is on work at, that is mechanical braking opening time. Before the right time to work, speed is still high and abrasion is still serious. After the right time to work, braking targets is hard to reach. To determine the mechanical braking opening time, electric braking effect and mechanical braking effect must be clear firstly.

4.1. Simulation result of electric braking

Assumed that initial velocity is 65km/h and electric braking is adopted solely, the simulation results are as follows.

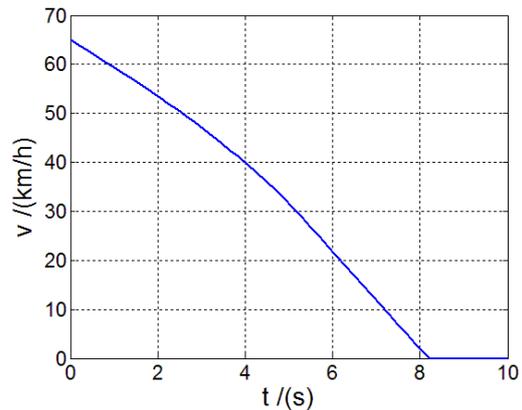


Figure 3: $v-t$ curve of electric braking

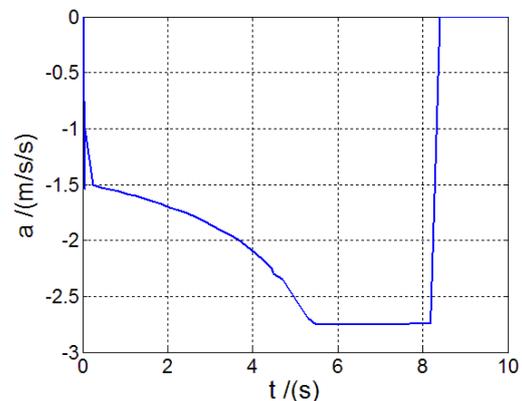


Figure 4: $a-t$ curve of electric braking

According to the curves, in electric braking condition, the vehicle needs 8.2s to decelerate from 65km/h to zero. Braking deceleration finally reaches $2.7 m/s^2$. Braking time and braking deceleration do not meet braking control targets.

4.2. Simulation result of mechanical braking

Assumed that initial velocity is 65km/h and mechanical braking is adopted solely, the simulation results are as follows.

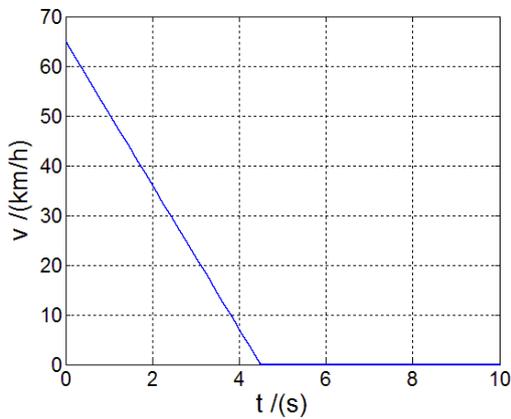


Figure 5: $v-t$ curve of mechanical braking

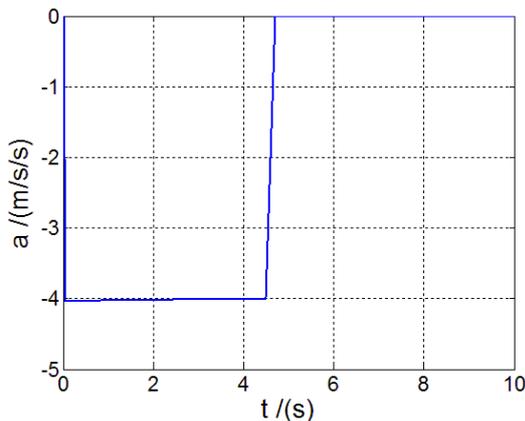


Figure 6: $a-t$ curve of mechanical braking

According to the curves of figure 5 and figure 6, in maximum mechanical braking force condition, the vehicle needs 4.4s to decelerate from 65km/h to zero. Braking deceleration quickly reaches $4 m/s^2$. Braking time and

braking deceleration do not meet braking control targets either.

4.3. Simulation result of electric-mechanical composite braking under ideal braking strategy

Assumed that initial velocity is 65km/h and the three-segment electric-mechanical composite braking strategy mentioned above is adopted. Suppose mechanical braking opening time of 1s that is the beginning of braking with electric braking separately, 1s after, the mechanical braking works to form electric-mechanical composite braking. When the speed dropped to a certain value, turn off motor, mechanical braking works solely to park vehicle. The simulation results are as follows.

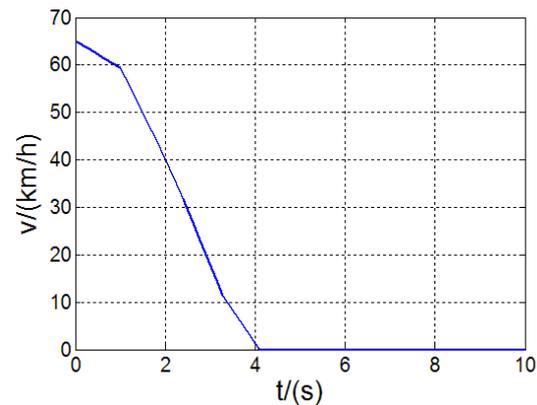


Figure 7: $v-t$ curve of three-segment composite braking

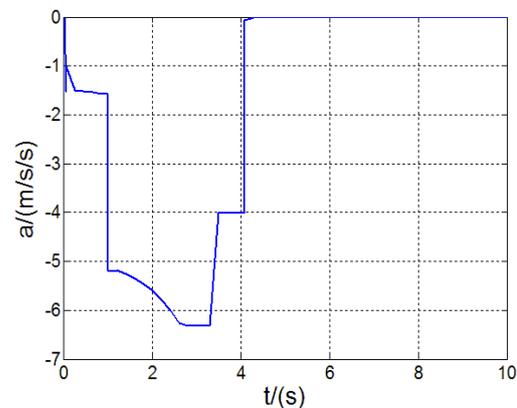


Figure 8: $a-t$ curve of three-segment composite braking

According to the curves of figure 7 and figure 8, in three-segment ideal braking strategy condition, the vehicle needs 4.1s to decelerate from 65km/h to zero. Braking deceleration reaches 6.31 m/s^2 . Although and braking deceleration is bigger than braking control target, braking time is not meet braking control target.

4.4. Two-segment electric-mechanical composite braking strategy

In order to achieve braking control targets, it is key to make sure the mechanical braking opening time. According to figure 7 and figure 8, when mechanical braking opening time is 1s, braking deceleration is much bigger than braking control target, but braking time is not meet the braking control target, that is to say that braking force is enough, but composite braking time is short and do not meet braking control target. Of course, mechanical braking opening time can be reduced right along to lengthen composite braking time to meet the braking control target. But this short mechanical braking opening time not only brings some difficult to control, but also can't reflect the advantages of electric braking alone. For mechanical braking, at the mechanical braking opening time, the speed of vehicle is still high and impact and friction is still serious, the advantage of composite braking is not obvious. So the three-segment ideal braking strategy is not fit for the tracked vehicle in the paper.

According to the characteristics of mechanical braking, electric braking and three-segment composite braking, electric braking force is small when high speed, and mechanical braking force isn't enough to meet braking control targets. While braking deceleration of three-segment composite braking is much bigger than braking target, which is waste.

From the above, according to braking control targets, a two-segment electric-mechanical

composite braking strategy is advanced:

1) At the beginning of braking, electric-mechanical composite braking is adopted to decelerate quickly;

2) When speed is decelerated to a certain degree, motors turn into low- efficiency area, turn off motors, mechanical braking works solely to make vehicle stand still.

5 Two-segment electric-mechanical composite braking strategy

Assumed that initial speed is 65km/h and the two-segment electric-mechanical composite braking strategy mentioned above is adopted. Simulation results are as follows.

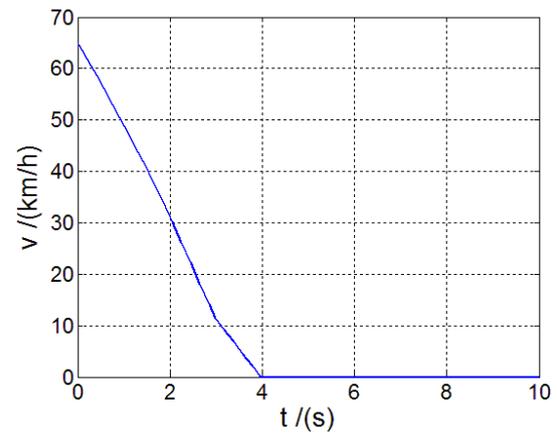


Figure 9: $v-t$ curve of two-segment composite braking

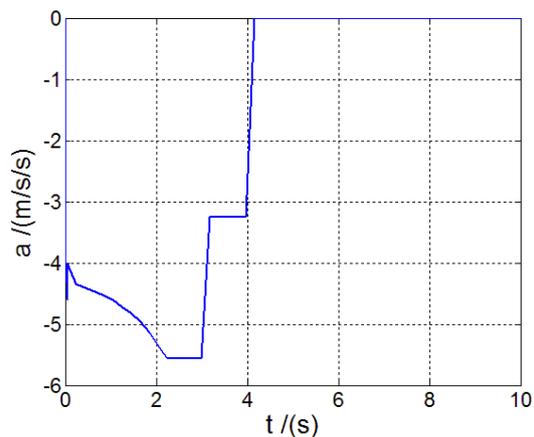


Figure 10: $a-t$ curve of two-segment composite braking

In figure 9, the time that speed decelerates from 65km/h to 0 is less than 4s. In figure 10, speed deceleration reaches $5.5m/s^2$. All these meet braking control targets. Although mechanical braking works all the time during braking, its braking force is part of its maximum braking force and electric braking reclaims a part of energy at high speed. Compared with pure mechanical braking, electric-mechanical composite braking on two-segment braking strategy is predominant.

As a measure standard of the braking effect, although the braking control target of braking distance is not mentioned in this paper, the braking distance is shorter, the braking effect is better. The braking distance of mechanical braking, electric braking, three-segment composite braking and two-segment composite braking are as follows.

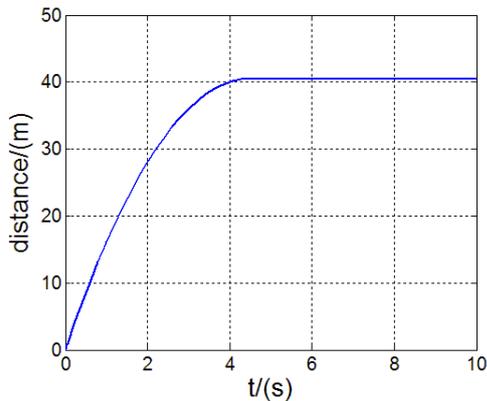


Figure 11: $v-t$ curve of mechanical braking

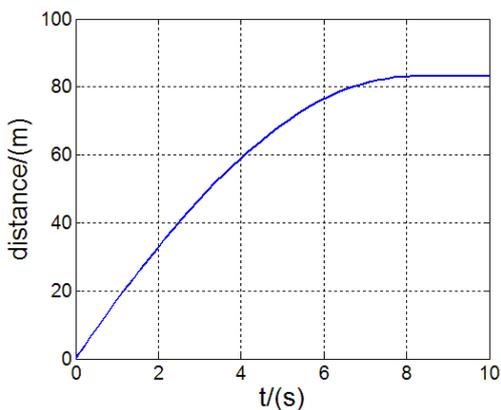


Figure 12: $a-t$ curve of electric braking

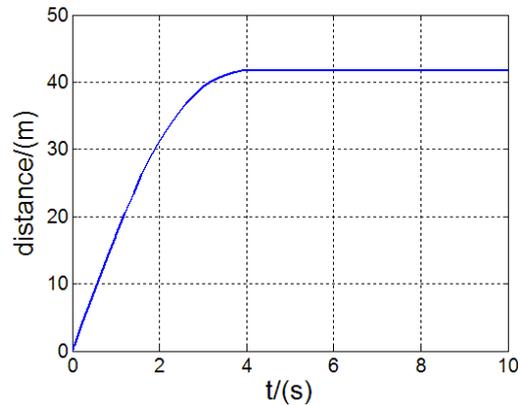


Figure 13: $v-t$ curve of three-segment composite braking

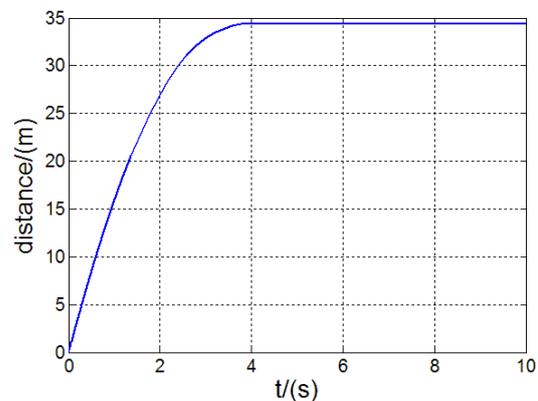


Figure 14: $a-t$ curve of two-segment composite braking

According to figures above, braking distance of mechanical braking is 40.5m, braking distance of electric braking is 83.1m, braking distance of three-segment composite braking is 41.7m and braking distance of two-segment composite braking is 34.4m. Braking distance of two-segment composite braking is the shortest. For the tracked vehicle in the paper, two-segment composite braking strategy is better for three-segment composite braking strategy according to braking distance.

The simulation speed curves of electric braking, mechanical braking of part mechanical braking force and two-segment electric-mechanical composite braking are plotted in figure 15. Mechanical braking supplies part of braking force, the other braking force is supplied by electric braking. Overlaying the two parts of

braking forces, composite braking speed curves is plotted. Electric braking speed curve is outboard and mechanical braking speed curve is in the middle, the essence of composite braking is that electric braking shares in some braking energy to solve long time braking problem and urgency braking problem, and this can enhance the dependability of braking system and improve braking efficiency.

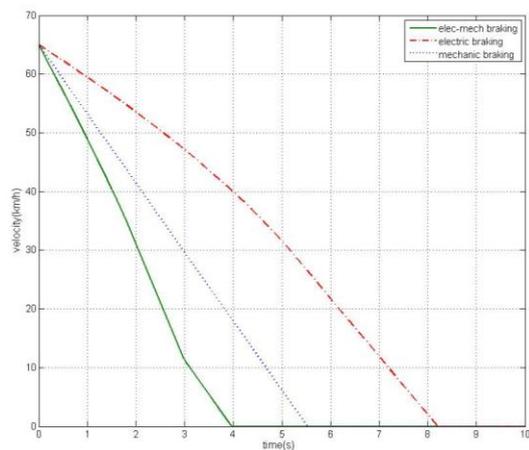


Figure 15: general $v-t$ curves of composite braking

6 Conclusions

(1) The three-segment electric-mechanical composite braking strategy of reference 1 is not fit for all hybrid tracked vehicle. Braking strategy should be based on practical condition. The two-segment electric-mechanical composite braking strategy advanced in this paper meets the braking control targets and decreases mechanical braking force. Anyway, the two-segment braking strategy improves the efficiency of mechanical braking and can reclaim some energy.

(2) The requirement of electrical system at driving and at braking is just the opposite. When low speed, big torque is required in order to start vehicle, while during braking, big torque is required at high speed to obtain big deceleration. The resolvent of the contradiction is impact with efficiency of electric-mechanic composite braking. The contradiction may be solved by improving motor design and the specific methods should be

studied.

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