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A Research on Regenerative Braking Control Strategy For Electric Bus

*1Liu Sheng, 2Cheng Lingshan
Shanghai University of Engineering Science,Shanghai,China
Corresponding Author: Liu Sheng

ABSTRACT: *On the basis of safe and stable braking, in order to effectively improve the urban electric bus brake energy recovery rate,with a rear drive 12 meters pure electric bus as the object,the vehicle braking dynamics and ECE regulations This paper presents a tandem regenerative braking control strategy based on the fully decoupled braking system.This strategy takes into account the influence of three factors such as battery SOC,vehicle speed and braking strength during the braking process,and ensures the safety and braking stability of the vehicle and improves the regenerative braking energy recovery rate and vehicle economy.The vehicle model and the regenerative braking control model are built by Matlab / Simulink, and the simulation is carried out.The simulation results show that the control strategy can significantly improve the braking energy recovery rate compared with the original control strategy.*

Keywords: *electric vehicle;regenerative brake; control strategy;Matlab/Simulink*

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I. Introduction

The 21st century is the era of low-carbon economy, hybrid cars and pure electric vehicles become the development trend of the automotive industry. Braking energy recovery technology to improve the energy efficiency, is the new energy vehicles to achieve driving range and energy saving and emission reduction one of the effective means. However, in the vehicle braking process, due to the participation of motor, will affect the vehicle safety, economy and comfort.[1]

The recovery of braking energy requires the consideration of the dynamic characteristics of the vehicle, the power generation characteristics of the motor and the charge and discharge characteristics of the power pack and the ECE regulations. So far, China's electric vehicle brake energy recovery control technology research focused on theoretical simulation, especially for urban electric bus brake energy recovery control research has just started. In this paper, a new type of tandem regeneration control strategy is proposed based on the improvement of the series regenerative braking control strategy from the perspective of the braking force distribution, and the 12m city pure electric bus driven by the rear wheel is used to verify its feasible Sexuality and practicality. In the brake safety and stability under the premise of effectively improving the energy recovery rate.

1 Vehicle braking dynamics and ECE regulations

1.1 Analysis of Vehicle Braking Dynamics

Choose 12 meters of urban electric bus as a research object, ignoring the impact of air resistance and rolling resistance, in the horizontal road brake force analysis shown in Figure 1:

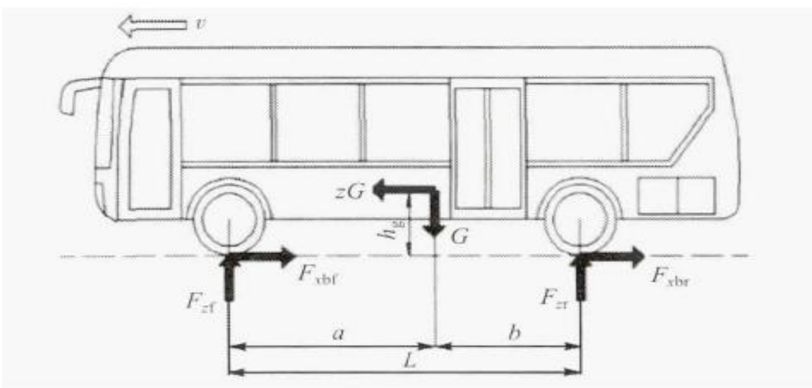


Figure 1 electric bus brake force analysis

Force analysis:

$F_{Zf} = \frac{G}{L}(b + zh_g)$(1)

$F_{Zr} = \frac{G}{L}(a - zh_g)$(2)

From formula (1) and (2), F_{Zf} and F_{Zr} are the normal reaction forces of the front and rear wheels when braking L is the wheelbase; a and b are the horizontal distance between the center of mass and the front and rear axles; hg is the mass center height; z is the braking strength.[2]

When the car brake, the front and rear wheels at the same time locked, you can get:

$F_{bf} + F_{br} = \varphi G$（3）

$F_{bf} = \varphi F_{Zf}$（4）

$F_{br} = \varphi F_{Zr}$（5）

Where F_{bf} and F_{br} are the front and rear wheel ground braking forces respectively, and φ is the road surface adhesion coefficient.

Eliminate φ can be:

$$F_{br} = \frac{1}{2}[\frac{G}{h_g}\sqrt{b^2 + \frac{4h_gL}{G}F_{bf}} - (\frac{G}{h_g} + 2F_{bf})]$$（6）

In the practical application, the front and rear axles are difficult to hold at the same time, which is ideal state. Therefore, the distribution coefficient of the braking force before and after the front and rear wheels is the ideal braking force distribution coefficient, the front and rear braking force distribution curve is the ideal braking force distribution curve, According to (6) to make the front and rear braking force distribution curve is the ideal front and rear axle braking force distribution curve, that is, I curve. Figure 2 for the vehicle at full load the front and rear axles ideal braking force distribution curve.[3]

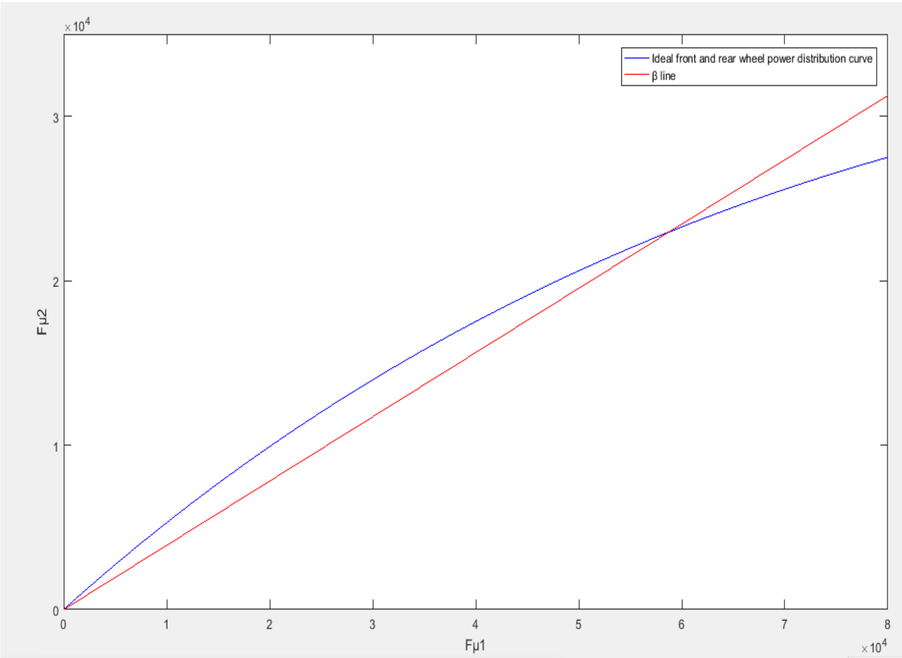


Figure2 the front and rear axles ideal braking force distribution curve

Many conventional front and rear axle braking force ratio is fixed, generally with the front axle braking force and the total braking force of the vehicle that the braking force distribution coefficient, expressed as β, namely:

$\beta = \frac{F_{bf}}{F_b} = \frac{F_{bf}}{F_{bf} + F_{br}}$（7）

Therefore, the curve of the $\frac{F_{bf}}{F_{br}} = \frac{\beta}{1+\beta}$, the front and rear axle braking forces according to the fixed ratio $\frac{\beta}{1+\beta}$ is called the β line. In order to prevent the rear wheel from locking, you should control the braking force distribution point under the I curve.

1.2 ECE regulations

The vehicle braking system should meet the driver's braking demand while ensuring the safety of the vehicle braking process. In order to ensure the safety of the vehicle during the braking process, the United Nations Economic Commission for Europe to develop the ECER13 brake regulations, ECER13 brake regulations on the front and rear axle braking power distribution made a clear request, the provisions of the front and rear axle power distribution The range of coefficients.[5]

According to ECER13 brake regulations on the requirements of M3 bus:

$$\begin{cases} \varphi_f > \varphi_r & 0.15 \le z \le 0.3 \\ Z - 0.08 \le \varphi_f \le z + 0.08 & 0.15 \le z \le 0.3 \\ \varphi_r \le z + 0.08 & 0.15 \le z \le 0.3 \\ \varphi_r \le \frac{z-0.02}{0.74} & 0.3 \le z \le 0.61 \\ \varphi_f \le \frac{z+0.07}{0.85} & 0.2 \le z \le 0.8 \\ \varphi_r \le \frac{z+0.07}{0.85} & 0.2 \le z \le 0.8 \end{cases} \quad (8)$$

The front and rear axes are substituted with the expression of the attachment factor:

$$\begin{cases} \beta > \frac{b+zh}{L} & 0.15 \le z \le 0.3 \\ \frac{(z-0.08)(b+zh)}{zL} \le \beta \le \frac{(z+0.08)(b+zh)}{zL} & 0.15 \le z \le 0.3 \\ \beta \ge 1 - \frac{(z+0.08)(a-zh)}{zL} & 0.15 \le z \le 0.3 \\ \beta \ge 1 - \frac{(z-0.02)(a-zh)}{0.74zL} & 0.3 \le z \le 0.61 \\ \beta \le \frac{(z+0.07)(b+zh)}{0.85zL} & 0.2 \le z \le 0.8 \\ \beta \ge 1 - \frac{(z+0.07)(a-zh)}{0.85zL} & 0.2 \le z \le 0.8 \end{cases} \quad (9)$$

2 Braking energy recovery control strategy

Series maximum braking energy recovery control strategy is to meet the ECE regulations under the conditions to maximize the use of motor regenerative braking. Braking strength is small, if the motor regenerative braking to meet the braking requirements, only by the regenerative braking force, not satisfied by the air brake to add. Brake strength is large, the front axle braking force is divided according to the lower limit of ECE regulations, the rear axle according to ECE regulations to determine the maximum allowable braking force, and the current motor to allow the regeneration braking force, take the smaller value for the actual motor regeneration system Power, rear axle brake force for the rear axle maximum braking force and the difference between the motor braking force.[6]The control strategy flow is shown in Figure 3.

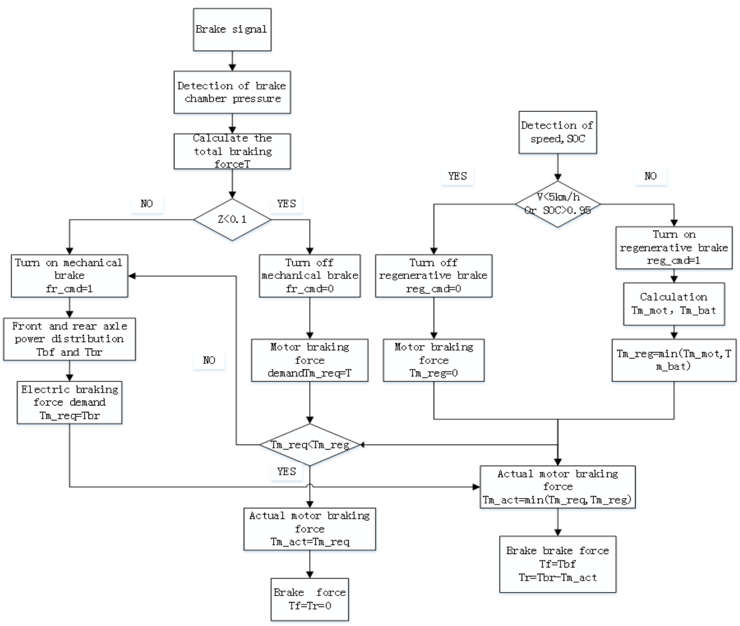


Figure 3 Control Strategy of Series Maximum Braking Energy Recovery

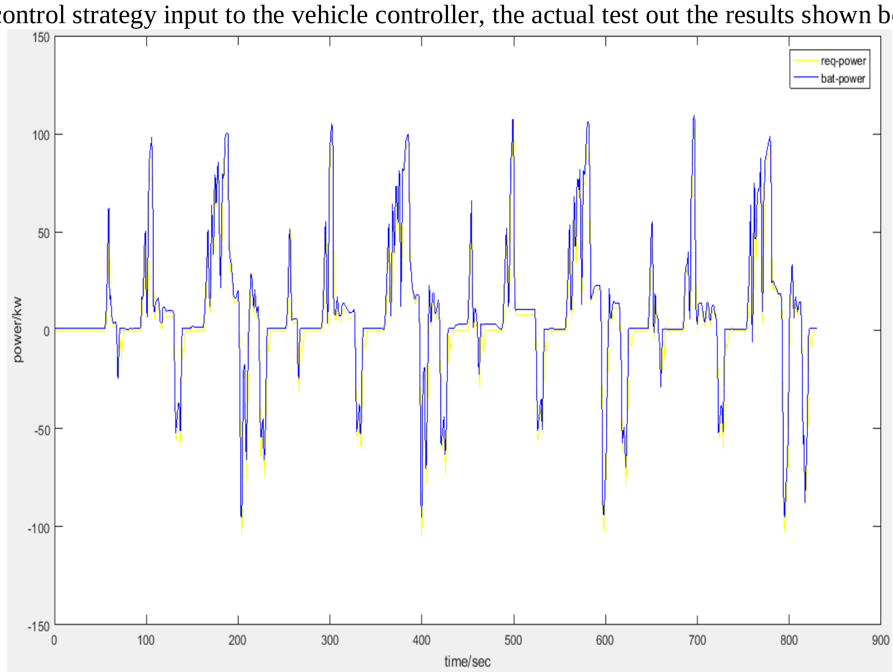
When the front and rear axle power distribution is performed, the upper limit Fbr0 of the rear axle braking force and the lower limit value Fbf0 of the front axle braking force are determined in accordance with the ECE rule, and the ideal front axle braking force Fbf1 and the rear axle braking force Fbr1 are calculated as necessary. In order to recycle the braking energy as much as possible, the rear axle is allocated as much of the motor brake as the conditions are met and the regulations permit. When the motor recovery capacity is limited, the front and rear axle braking force is distributed according to the ideal braking force distribution curve, and the braking stability is improved. The following is an analysis of the mechanical braking force of the front and rear axles and the determination of the motor braking force.

(1)When z≤0.1,Fbr0=Fb;Fbf0=0;ifFm_reg≥Fbr0,Fm_act=Fb,Fbr=0;Fbf=0;
ifFm_reg<Fbr0,Fm_act=Fm_reg,Fbr=0;Fbf=Fb-Fm_reg;
(2)When 0.1<z≤0.3,Fbr0=Fb*（a-z*hg）/L;Fbf0=Fb-Fbr0;
if Fm_reg≥Fbr0,Fm_act=Fbr0,Fbr=0;Fbf=Fb-Fbr0;
if Fm_reg<Fbr0,Fm_act=Fm_reg,Fbr=Fbr0-Fm_reg;Fbf=Fb-Fbr0;
(3)When 0.3<z≤0.61,u=（z-0.02）/0.74,Fbr0=u*G*（a-z*hg）/L;Fbf0=Fb-Fbr0;Fbr1=Fb*（a-z*hg）/L;Fbf1=Fb-Fbr1;
ifFm_reg≥Fbr0,Fm_act=Fbr0,Fbr=0;Fbf=Fb-Fbr0;
if Fbr1<Fm_reg<Fbr0,Fm_act=Fm_reg,Fbr=0;Fbf=Fb-Fm_reg;
ifFm_reg≤Fbr1,Fm_act=Fm_reg,Fbr=Fbr1-Fm_reg;Fbf=Fb-Fbr1;
(4)When 0.61<z≤0.8,Fbr0=0.8*G*（a-z*hg）/L;Fbf0=Fb-Fbr0;Fbr1=Fb*（a-z*hg）/L;Fbf1=Fb-Fbr1;
if Fm_reg≥Fbr0,Fm_act=Fbr0,Fbr=0;Fbf=Fb-Fbr0;
if Fbr1<Fm_reg<Fbr0,Fm_act=Fm_reg,Fbr=0;Fbf=Fb-Fm_reg;
if Fm_reg≤Fbr1,Fm_act=Fm_reg,Fbr=Fbr1-Fm_reg;Fbf=Fb-Fbr1;

3 control strategy simulation and results

Using Matlab / Simulink simulation software, the backward simulation modeling method and the control algorithm based on nonlinear programming are used to simulate the braking energy recovery control strategy. The working conditions adopted are typical traffic conditions in Shanghai.

The control strategy input to the vehicle controller, the actual test out the results shown below:



Through the calculation, the braking energy recovery rate can reach 82%, and on the basis of simple parallel control strategy, it is about 20 percentage points to prove the rationality and feasibility of the new series control strategy.

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