Design of increasing controllability of braking vehicle

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Abstract: The operating principle of an antilock braking system (ABS) is it compares current value of angular acceleration with the threshold value. The advantage of such system is that enough it has only the angular velocity sensors. The disadvantage is successive overshoot, i. e. successive transition from wheels locking mode to wheels rolling mode. So braking mechanism can't realize the maximum possible torque in the current road conditions. The idea of increasing the braking effectiveness is the intensity of rising pressure depends on the road conditions. The problem is the torque produced by braking mechanism, current road conditions and the value of traction coefficient is unknown. For evaluation of these parameters built and training three neural networks. A simulator of random road condition's variation was built to test adequacy of the control unit's operation in close to real conditions.

Key words: antilock braking system (ABS); model of braking vehicle; parameter identification; simulation experiment

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0 Introduction

Road safety depends on the reliability and efficiency of braking systems. Therefore, improving the braking system is an important factor in reducing the number and severity of road accidents. The function of antilock braking system (ABS) is to prevent the full block of wheels, thus increasing controllability of the vehicle and reducing braking distance. If the wheel is locked, the vehicle will brake in the skid mode. In this case, energy is expended not in the braking mechanism, but in the wheel-road contact patch. In this mode, the wheel tire suffers heavy wear, the efficiency of braking decreases, however the most important issue is that the driver has loses control of the vehicle. If the road surface is slippery, for example ice, even if using the maximum realizable braking torque, the braking distance will be very long. Therefore, the measures for increasing traction coefficient should be accepted. Thus, under winter conditions, when road has a slippery surface, special winter spiked tires should be used.

The analysis of articles reveals some imperfections in the mathematical models of much research, shown by the graphs. For example, the model spended about 15 s for braking from the velocity of 50 km/h till stop in Refs. [1-2]. The braking distance exceeded 120 m in Ref. [3]. In some models, angular velocity began to rise after braking started and exceeded the velocity of vehicle body[4]. It can be seen that some authors devoted little attention to building an adequate model of vehicle braking. Since mathematical models are the base of all simulation, the creation of adequate models is the most important part of research. Therefore, much time of research was devoted to building a mathematical model.

1 Mathematical description of automobile braking

Fig. 1 shows a scheme of forces influencing the wheel during movement on a horizontal surface.

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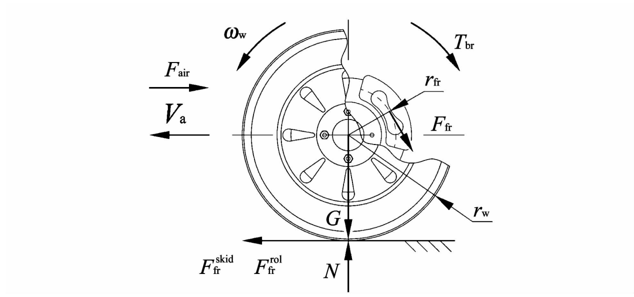

Fig. 1 Scheme of forces influencing wheel

where V_a is linear velocity of vehicle's center of mass, m/s; ω_w is angular velocity of wheel, rad/s; r_w is wheel radius, m; T_{br} is braking torque produced by mechanism, N·m; G is weight of vehicle on wheel, N; F_{air} is aerodynamic force, N; N is normal reaction of surface, N; F_{fr}^{rol} is friction force of wheels rolling, N; F_{fr}^{skid} is friction force during skidding, N; F_{fr} is friction force in braking mechanism, N; and r_{fr} is middle radius of friction in braking mechanism, m.

The mathematical description of automobile which is moving on the horizontal support surface during braking (equal energy balance) is given by

$$\begin{cases} E_k - W_{br} - W_{air} - W_{fr}^{rol} - W_{fr}^{skid} = 0, \\ E_k = \frac{V_a^2 m_a}{2} \pm \frac{\omega_w^2 I_{tr}}{2}, \\ W_{br} = T_{br} \omega t, \\ W_{air} = F_{air} L, \\ W_{fr}^{rol} = F_{fr}^{rol} L \eta, \\ W_{fr}^{skid} = F_{fr}^{skid} L, \end{cases} \quad (1)$$

where E_k is kinetic energy stored by vehicle, J; m_a is mass of automobile, kg; I_{tr} is inertia of wheels and transmission, kg/m^2; W_{br} is work of braking force, J; t is time of braking, s; W_{air} is work of aerodynamic force, J; L is distance, m; W_{fr}^{rol} is work of friction force at wheels rolling, J; η is energy conversion efficiency in transmission; and W_{fr}^{skid} is work of friction force during skid, J.

The maximum braking torque in current road condition is described by

$$T_{max} = N r_w \varphi, \quad (2)$$

where φ is traction coefficient.

The braking torque produced by baking is

$$T_{br} = F_{fr} r_{fr}. \quad (3)$$

The friction force in braking mechanism is

$$F_{fr} = F_{br} f_{mech}, \quad (4)$$

where F_{br} is press force in braking mechanism, N; and f_{mech} is coefficient of slip friction in friction pair of braking mechanism.

The coefficient of longitudinal slip is calculated by

$$S_w = \frac{V_a - \omega_w r_w}{V_a}. \quad (5)$$

To accurately measure the linear speed of auto mobile, the methodology based on the use of on-board radar is encouraged[5].

2 Development of control unit with increased work efficiency

As a result of analysis of literature, the following relationships were discovered. Maximum realizable braking torque depends on traction coefficient, which depends on road conditions as well as velocity of vehicle[6-7]. The coefficient of friction in the braking mechanism depends on the vehicle's velocity and the temperature of friction pair[8-10]. These relationships were approximated using MathCAD. The values of data arrays were calculated by using obtained polynomials.

The developed system involves installation of temperature sensors on friction pads in the braking mechanisms. For chosen material of brake pad, the dependence of friction coefficient vs. velocity and temperature is presented in Fig. 2.

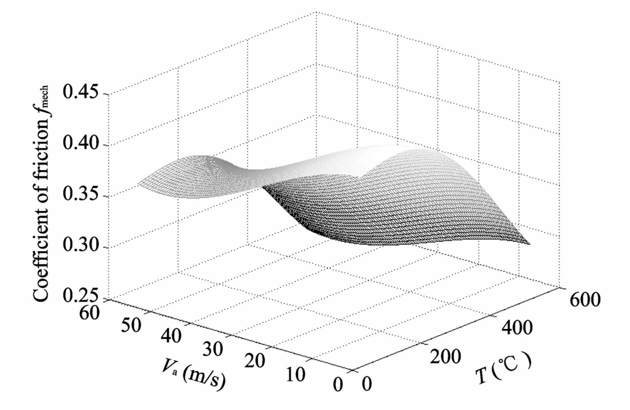

Fig. 2 Graph of dependence coefficient of friction in braking mechanism vs. velocity and temperature

To measure the temperature of the friction pad, the use of fast response surface temperature sensor is encouraged[11].

Fig. 3 shows the dependence of the traction coefficient vs. velocity for different road conditions. Different road conditions presented on the graph is in the axel of the road surface *surf*. For example, dry asphalt is 1, wet asphalt is 0. 8, unpacked snow is 0. 4, ice is 0. 3, and other types of surfaces in interim.

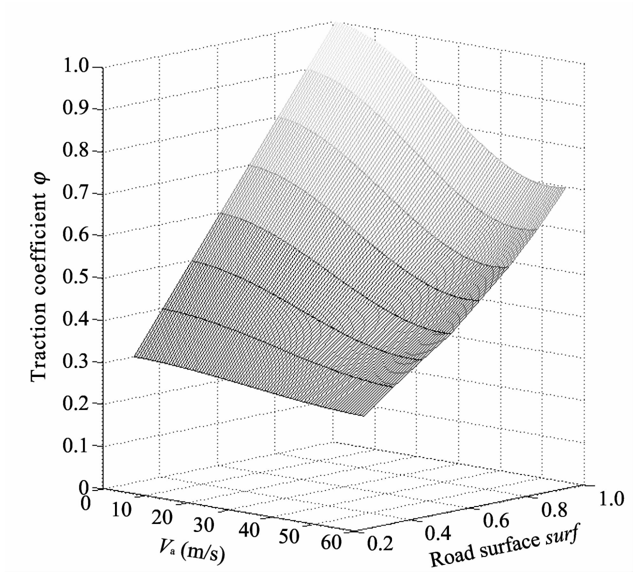

Fig. 3 Graph of traction coefficient vs. velocity in different road conditions

The idea of increasing braking effectiveness is the intensity of rising pressure that depends on the road conditions. For example, the system under discuss will operate like initial system in poor road conditions, but during improvement of road conditions, the intensity of rising pressure will be reduced. Thereby in good road conditions, the wheel will slowly lock and brakes will have the largest work of friction in an equal time interval, which improves the efficiency of braking. This dependence can be described by

$$intF = a_1 surf^1 + a_2 surf^2 + a_3 surf^3 + a_4 surf^4,$$

where a_1, a_2, a_3 and a_4 are picked coefficients.

Fig. 4 shows the dependence of the intensity of actuator's pressure rising ($intF$) vs. type of road surface. If the quality of the road's surface exceeds 0. 3, the intensity of rising pressure will begin to decline and will lower about ten times in good road conditions.

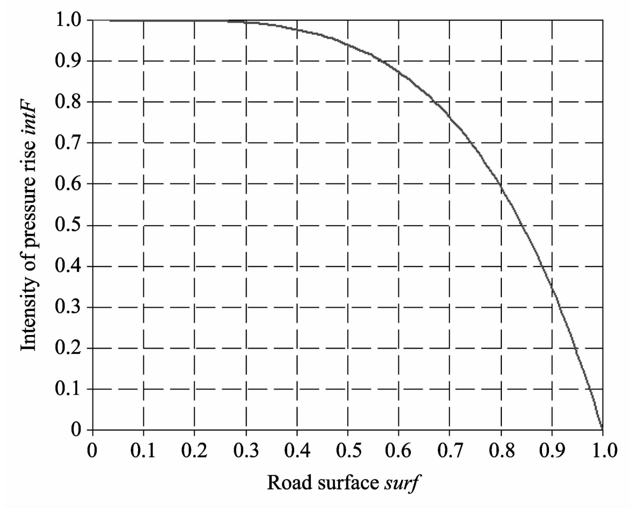

Fig. 4 Dependence of intensity of actuator's pressure rising vs. current road conditions

The control unit calculates quantity of holding's interval according to Eq. (6), namely

$$N_{hold} = 10 - 10intF. \quad (6)$$

According to Fig. 4 and Eq. (6), if the road condition is close to 1 (dry asphalt), the control unit will transmit a signal to terminate the increase of pressure in the operating cylinder and hold it at current level (signal "HOLD").

If pressure rising starts, the control unit will begin to reduce the intensity of rising pressure and it will slowly proceed or even stop rising in good road conditions. Therefore, the control unit needs the threshold of activation to eliminate this effect. Supposing the threshold is a constant, if the threshold value is low, the process of rising braking torque will quickly stop. Especially in good road conditions, braking will be ineffective. If the threshold value is high, decrease of intensity will be weak in bad road conditions. As a result, the control unit will be ineffective. Therefore, the dynamic threshold is added in the model depending on current road conditions.

Two-layer networks have been built for the estimation of unknown parameters. Networks type indudes feed forward and back propagation. Transfer functions are hyperbolic tangent sigmoid in the first layer and linear in the second layer.

The first neural network estimates type of road condition, the second neural network estimates the current value of traction coefficient, and the third neural network estimates the value of friction coefficient in the braking mechanism.

The relationships in Figs. 2 and 3 are approximated using MathCAD. The values of arrays of input data and target data for training neural network are calculated by using obtained polynomials by MathCAD.

Fig. 5 shows the variation of activation threshold *act* by the current road condition.

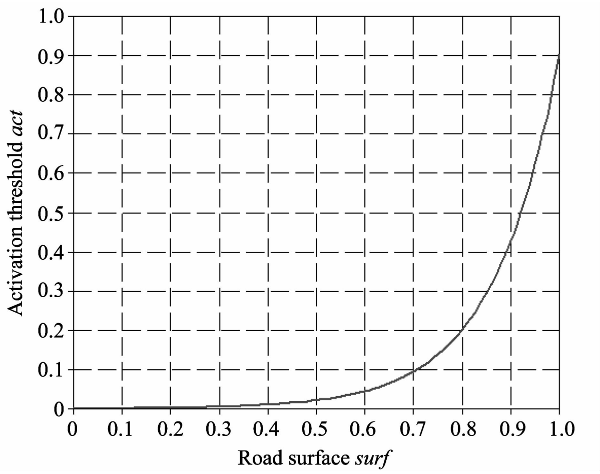

Fig. 5 Variation of activation threshold by current road condition

The mathematical model contains the block which calculates the current value of traction coefficient at the begining of locking process, that is, at the moment of blocking. The first neural network estimates the type of road condition using linear velocity sensor's data and value of traction coefficient at the beginning of blocking. If road conditions do not change but velocity changes, the second neural network will estimate the current value of traction coefficient according to the value of velocity and the type of road surface. The third neural network estimates the value of friction coefficient in the braking mechanism using the value of velocity and the value of braking pad's temperature. Then, using data estimated by the second neural network, the control unit calculates the maximum realizable braking torque in current road condition, namely

$$T_{\max}=Nr_{\mathrm{w}}\varphi'. \tag{7}$$

Using data estimated by the third neural network, the control unit calculates the value of current braking torque in braking mechanism, namely

$$T_{\mathrm{br}}=F_{\mathrm{br}}r_{\mathrm{fr}}f'_{\mathrm{mech}}. \tag{8}$$

The control period has been divided into 10 intervals, thus the frequency of comparing acceleration with threshold logical unit is ten times longer than the frequency of comparing acceleration with the following units. Therefore, one cycle of comparing acceleration with threshold is fit for ten cycles of setting the control signal. For example, the value of angular acceleration is less than -200 rad/s^2, which means the blocking process begins. The control unit calculates current value of traction coefficient according to Eq. (8), namely

$$\varphi_{\mathrm{block}}=\frac{T'_{\mathrm{br}}}{Gr_{\mathrm{w}}}. \tag{9}$$

The control unit under discuss operates according to the algorithm presented in Fig. 6.

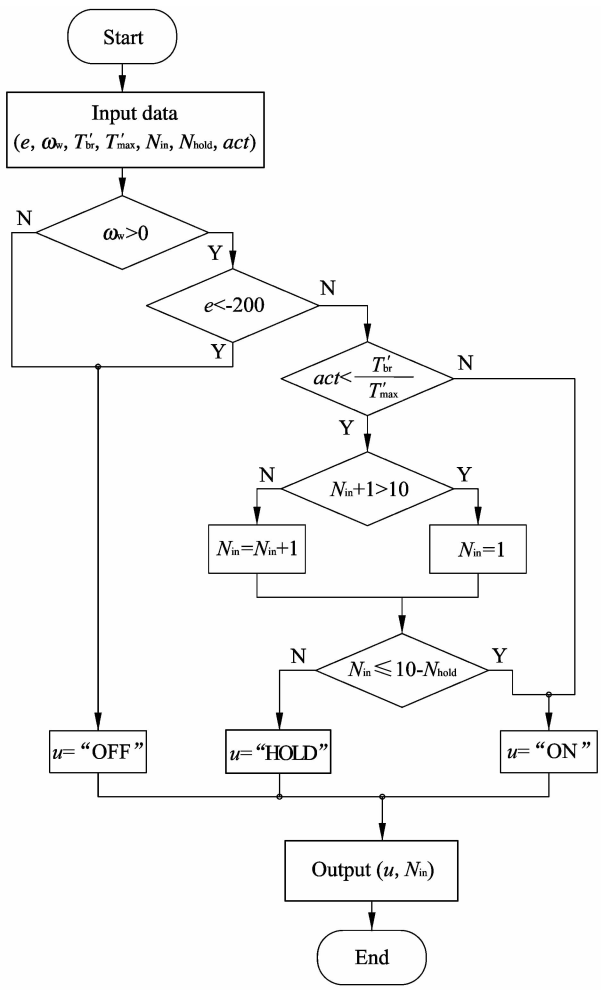

Fig. 6 Algorithm flow chart of control unit

Neural networks evaluate current values of the variables, then the control unit compares the ratio between calculated current braking torque T'_{br} and calculated maximum braking torque T'_{max} with activation threshold *act*. If this ratio exceeds the threshold, the control unit will compare quantity of holding's interval N_{hold} with current index number of interval N. If the current index number of interval does not exceed quantity of the holding's interval, the control unit will transmit the signal "increase pressure" ("ON"), or else it will transmit signal "hold pressure" ("HOLD").

Fig. 7 shows a block diagram of the control unit under discuss.

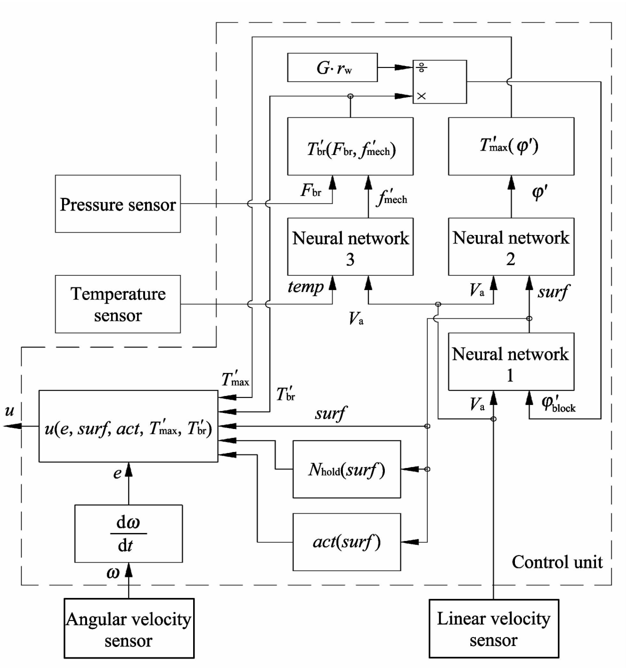

Fig. 7 Block diagram of control unit

If road conditions deteriorate, the wheel will begin to block, and then the control system will detect the exceeded threshold according to the value of angular acceleration of the wheel. Based on this, it sends the signal to decrease pressure, the operation will be repeated circularly.

In good road conditions, change of the traction coefficient will be within a few percent and wheel will not begin locking. Thus, the braking system will operate closer to realization of the maximum possible braking torque in current road conditions.

Some researchers simulate braking only in constant road conditions, which is incorrect because in real conditions the maximum value of the traction coefficient greatly varies with which type of road surface and the cleanliness of the road surface. Therefore, to check effectiveness of the model in almost real conditions, the simulator of variable of road surface quality is built in Simulink. Fig. 8 shows the graph of the varied maximum value of traction coefficient.

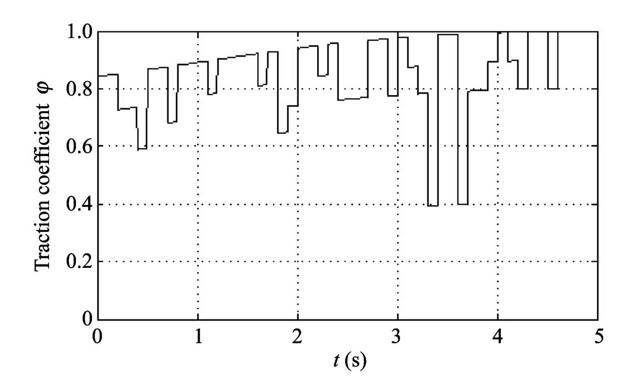

Fig. 8 Graph of varied road conditions

This block changes the value of the maximum traction coefficient by the type of road surface, which synchronizes a random number generator.

3 Simulation

Comparison of the simulation results of the braking system by the initial control unit and the control unit under discuss in variable road conditions is shown in Figs. 9—12. The graphs of varied linear velocity of the vehicle during braking in variable road conditions are shown in Fig. 9.

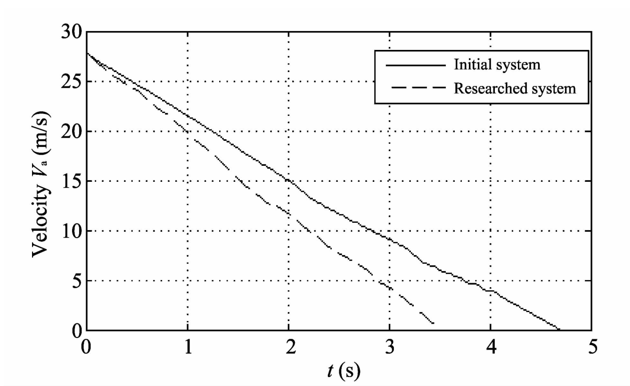

Fig. 9 Graphs of linear velocity

As seen from the comparison of changing linear velocity graphs, braking time has been reduced by using the control unit under discuss. As a result, braking distance has also been reduced. This shows a very important index of increasing braking system's effectiveness and road safety. Fig. 10 shows the graphs of braking distance during braking in variable road conditions.

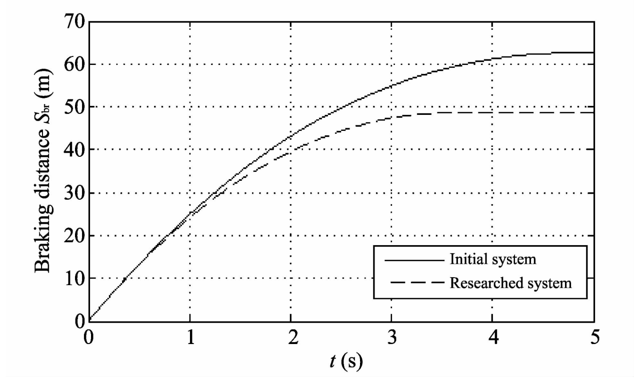

Fig. 10 Graphs of braking distance

Fig. 11 shows the graphs of changing angular velocity during braking in variable road conditions.

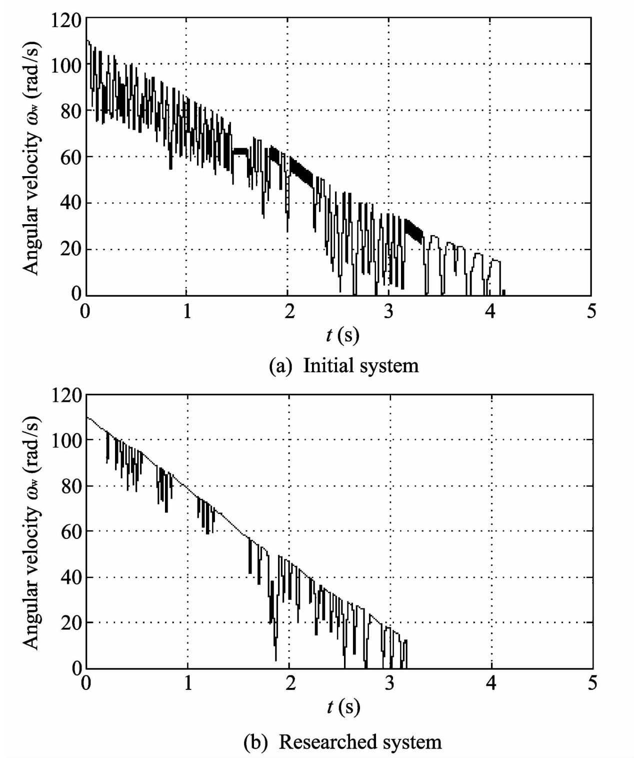

Fig. 11 Graphs of changing angular velocity

As seen from comparison of graphs of angular velocity during braking by the initial control unit and the researched control unit, the second braking system is better in preventing wheel locking in variable road condition. On the final stage, the fall of angular velocity to zero results in switch to permanent braking mode (velocity is less then 12 km/h).

Fig. 12 shows the graphs of changing coefficient of longitudinal slipping during braking by the variable road conditions.

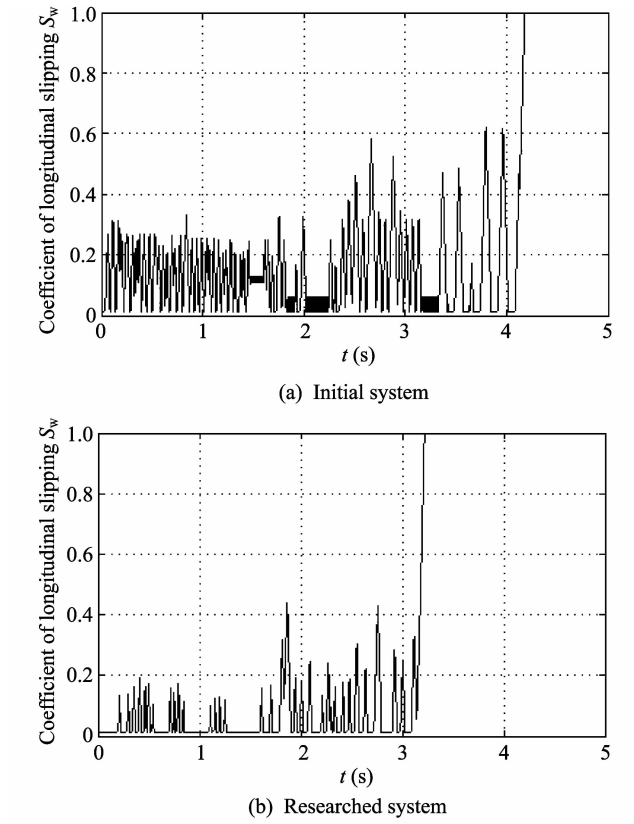

Fig. 12 Graphs of changing coefficient of longitudinal slipping

Comparison of changing values of longitudinal slipping during braking of initial control unit and the control unit under discuss shows that the time of wheels locking is reduced and wheels are not once locked till the control unit is switched to permanent braking mode.

As a result, the problem of increasing vehicle controllability during braking is solved.

4 Conclusion

The mathematical description of automobile braking is created along with the mathematical model in Simulink. The initial control unit built in Simulink compares current value with the threshold value of angular acceleration. If it exceeds the threshold value, the control unit will transmit a signal to the hydraulic modulator. On the basis of simulation results, conclusion about the shortcomings of the control unit can be drawn. Next, the method of improving the working efficiency of the control unit is developed by using additional information about the current state of the object. The control unit with increased effectiveness is built. For checking accuracy of the model, a simulator of variable road surface's quality close to real conditions is built. As seen from the graphs of the simulation results, braking distance is reduced and the coefficient longitudinal slipping has dropped. Accordingly, the task of improving the car's handling during braking is executed.

References

[1] LI Fa-zong, HU Ru-fu, YAO Huan-xin. The performance of automobile antilock brake system based on fuzzy robust control. In: Proceedings of IEEE Inernational Conference on Intelligent Computation Technology and Automation, Changsha, 2010, 3: 871-873.

[2] LI Guo, SUN Yan, WANG Hui. The synchronous adaptive fuzzy control for the vehicle steering/Anti-lock Brake System. In: Proceedings of IEEE 32nd Chinese Control Conference, Xi'an, 2013: 3047-3052.

[3] WANG Ji, SONG Chuan-xue, JIN Li-qiang. Modeling and simulation of automotive four-channel hydraulic ABS based on AMESim and Simulink/Stateflow. In: Proceedings of IEEE International Workshop on Intelligent System and Automation, Wuhan, 2010: 1-4.

[4] Aly A A. Intelligent fuzzy control for antilock brake syste with road-surfaces identifier. In: Proceedings of IEEE International Conference on Mechatronics and Automation, Xi'an, 2010, 1(3): 699-705.

[5] Ananenkov A E, Thanh B C, Gerasimov L A, et al. Evaluation of vehicle movement speed by means of the automobile radar data. In: Proceedings of IEEE International Conference on Transparent Optical Networks, Budapest, 2015: 1-4.

[6] Aguilar-Martíneza J, Alvarez-Icazab L. Analysis of tire-road contact area in a control oriented test bed for dynamic friction models. Journal of Applied Research and Technology, 2015, 13(4): 461-462.

[7] CHEN Hua, Ban T, Ishida M, et al. Influential factors on adhesion between wheel and rail under wet conditions. Wear. Quarterly Report of Rtri, 2008, 265(9): 1504-1511.

[8] Lee N J, Kang C G. The effect of a variable disc pad friction coefficient for the mechanic brake system of a railway vehicle. PLoS One, 2015, 10(8): 4-5.

[9] Sugozu I, Mutlu I, Sugozu K B. The effect of ulexite to the tribological properties of brake lining materials. Polymer Composities, 2015, 37(4): 3-5.

[10] ZHANG Jun-zhan, XU Yong-dong, ZHANG Li-tong. Effect of braking speed on friction and wear behaviors of C/C-SiC composites. Applied Ceramic Technology, 2007, 4(5): 463-469.

[11] Mohhamed H A, Yusoff M Z, Hanim S. Fast response surface temperature sensor for hypersonic vehicles. Instruments and Experimental Techniques, 2010, 53(1): 153-159.

增加车辆刹车可控性设计

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摘　要： 防抱死制动系统(Antilock braking system, ABS)是通过车轮角加速度与阈限值的比较进行制动力控制。这种系统的优势是只需角速度传感器信号就足够了；缺点是工作时会出现制动压力连续的超调，使车轮从抱死模式到滚动模式来回转换，这样制动器不能产生在当前道路状况下最大可能的制动力矩值。增加制动效率的构思是制动压力增加的强度取决于当前道路状况，但面临的问题是制动器产生的制动力矩值、当前道路状况和牵引系数值是未知数。本文通过建立三层神经网络模型来识别和获取这些参数，并在设计的随机路面上进行仿真实验，验证了所设计控制器工作的准确性。

关键词： 防抱死制动系统；车辆制动模型；参数识别；仿真实验

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