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The Design and Simulation of the Modular Vehicle Air Suspension Height Control System Based on ECAS

[1] Yang Peigang, [2] Bao Jianming, [1] Jiang Ruibin,
[1] Xiong Shaohua, [1] Diao Yifeng

[1] Vehicle Engineering Department, Hunan Biological and Electromechanical Polytechnic, Changsha 410126, China
[2] Special Vehicles Department, Dongfeng Automobile Co., Ltd. Wuhan 430056, China
E-mail: 5229889@qq.com

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Abstract: Based on ECAS, this paper intended to develop a modular air suspension height control system with WABCO4728800010 two-position three way solenoid valves and Free scale MC9S12D64 microprocessor as its core components. And a simulation test was conducted in MATLAB/Simulink environment. The air suspension height control strategy of this system was divided into four modules: start control module, dynamic adjustment module, manual adjustment module and errors adjustment module, which were controlled by module select switch. Simulation tests indicated that the air suspension height control strategy is featured by its logical control accuracy and debug convenience, and the modular design greatly reduced the system complexity and software development cycle and costs as well. *Copyright © 2014 IFSA Publishing, S. L.*

Keywords: ECAS, Modular, Air suspension, Suspension height control, Simulink simulation.

1. Introduction

Electronic Controlled Air Suspension (ECAS) may greatly improve the ride comfort and handling stability of vehicles as well as reduce heavily loaded vehicles' damages to the roads [1] by performing multi-functions with the electronic control system and changing suspension parameters when the driving cycle changes, therefore it can help protect both vehicles and roads. Nowadays nearly all the buses abroad have been using air suspension, and the percentage is up to 80 % or higher even for the heavily loaded vehicles. Actually, air suspension is almost the only choice for vehicles with specific requirements, and in the early 1990s, many countries had been using the electronic-controlled air suspension system [2]. In recent years, our country has started to use ECAS for commercial vehicles especially for city buses and travel buses, however, the equipping rate is relatively low which is mainly restrained by the cost and the reliability. Among the controlling functions in ECAS, height control strategy is the core component. If the chassis height frequently adjusted, it is probable that air pump system has to stand local overheating which would greatly shorten its service time [3]. The complexity of the ECAS control system is varying from vehicle to vehicle, and from structure to structure. For commercial vehicles, the frequently used structures includes double axle air suspension, the front axle integration control, the rear axle's or the front axle's separate control and the rear axle integration control, from which it is obvious to see that only the front and the rear axle are equipped with the air suspension and are separately controlled. In this paper, the author intends to discuss modular designing strategy of

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ECAS control system by illustrating a typical commercial vehicle with rear axle equipped with air suspension. By choosing different function modules based on different demands from clients, the whole vehicle's performance requirements can be successfully met, therefore, modular control system would greatly reduce its complexity and software's developing cycle and costs.

2. Air Suspension System's Height Controlling Structure

As shown in Fig. 1, the air suspension system adopts the diaphragm type air spring, WABCO4728800010 two position three way solenoid valves, Hall type height sensor, ECU with MC9S12D64 microprocessor from Free scale Corp. ECU can receive signals from vehicle height sensor, speed sensor and other sensors as well and then decide the output state of the control instruction through the logical judgments of the system control strategy. Control instruction is decisive for the inflating, deflating and the enclosing of the airbag mainly through the level position control of the solenoid valves and solenoid coils.

The ECU input signal types can be divided into continuous signals (including height sensor signals and speed signals) and switching signals (including pressure sensor signals, ignition signals, braking signals, doors position signals and control signals), while the operation panel buttons contain M1 (Special height H1), M2 (Special height H2), Normal (Normal height H0), Lifting, Lowering, STOP. ECU output signals include valves control instructions and indicators (e.g. height indicators, warning lamp, safety lamp).

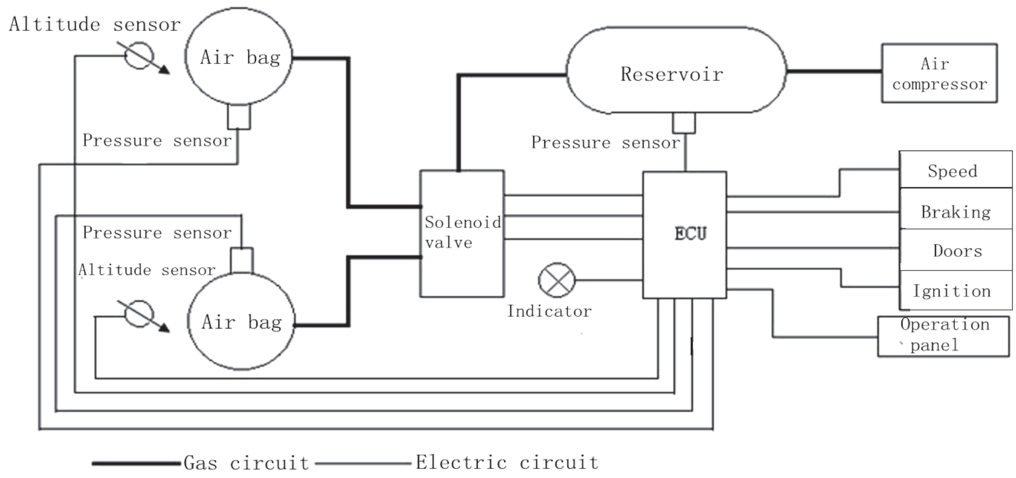

Fig. 1. Structure of the Air Suspension System.

The calibration parameters in the system is Hmax_height, Hmin_height, normal height H0, special height H1, special height H2, H_deviation, L_R_deviation, speed threshold value for controlling special height H1 (speed 1), speed threshold value for recovering standard height (speed 2), speed threshold value for controlling manual switch (V_m) and so on.

The solenoid valves' circuit of internal wiring can be shown in Fig. 2. The solenoid valves altogether have three vents, one for intake (11) and another two for exhaust (22/23), therefore the circuit of internal wiring only suit for the controlling of two airbags with the same axle. In Fig. 2, the gas path 21 is plugged by the bolt, gas path 22 is for 2-HAS axle's (rear axle) left airbag, the Fig. 2 stands for exhaust muffler, and the solenoid valves have four core wires, that is, 6.1, 6.2, 6.3, 6.4 respectively, among which 6.1 is the main control valve coils, 6.2 is the valve coil for controlling gas path 22 while 6.3 is for controlling gas path 23; the airbag's opening and enclosing depends on the mainly-controlled valve and its corresponding controlled valve.

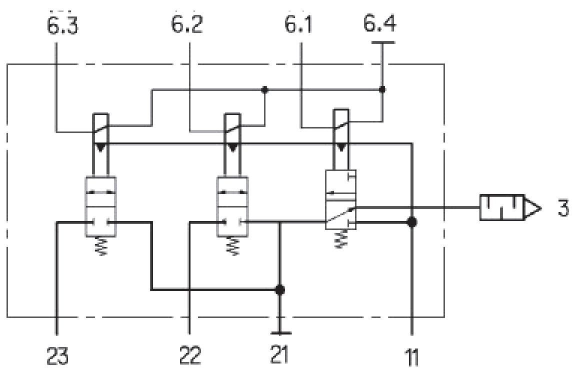

Fig. 2. The Solenoid Valve Circuit of Internal Wiring.

3. Strategy Design for Height Control

The height of ECAS has three types, that is, normal height H0, special height H1, special height H2. Besides, in order to limit the suspension movement distance, it is necessary to set the upper and lower limit of the height. The so-called normal height is the designing height when the air spring manufactured, while special height H1 is usually lower than H0, H2 is higher than H0, for which the height can be modified according to the whole vehicles' matching demands.

According to the idea of modular design, the height control strategy can be divided into start control module, dynamic adjustment module, manual adjustment module and also error adjustment module. Choosing different control module is functioned by module selection switch which can judge vehicle condition and select the corresponding control module based on vehicle speed and ignition signals and then control the airbag height, hence the vehicle height under such situation can be adjusted.

3.1. Start Control Module

1) Functions: The system will automatically detect manual control signals and height signals. If no manual control signals detected, it will automatically adjust to the normal height H0; only special height H1 and H2 can be selected for the manual switch.

2) Call condition: V=0, Ignition=1.

3) Input signals: speed signals, ignition signals, height sensor signals, control signals M1 and M2.

4) Output signals: The control signals from solenoid coils 6.1, 6.2, 6.3.

3.2. Dynamic Adjustment Modules

1) Functions: The system will take an automatic adjustment when vehicle speed is beyond limit value Vm (this value can be calibrated based on different needs), at the same time no detection for the manual signals, that is, manual control will fail to function. The specific details can be listed as follows: the system will adjust the vehicle height to normal height H0 when speed is relatively low but still above V_m (Normally 20 km/h would be considered); to special height H1 when speed is above speed value (speed 1) for controlling special height H1; and back to normal H0 when speed is lower than speed value (speed 2) for recovering to normal height.

2) Call condition: $V>V_m$.

3) Input signals: height sensor signals, speed signals.

4) Output signals: The control signals from solenoid coils 6.1, 6.2, 6.3.

3.3. Manual Adjustment Modules

1) Functions: When speed is in an interval between 0-Vm, the driver may manually control the height with control buttons and there will be no automatic adjustment for the system until speed is above speed value for manual control.

2) Call condition: 0<V< Vm.

3) Input signals: speed signals, height sensor signals, control button signals (H0, H1, H2, Lifting, Lowering, STOP).

4) Output signals: The control signals from solenoid coils 6.1, 6.2, 6.3.

3.4. Error Adjustment Modules

1) Functions: In the height adjustment procedures, the module will ensure the height deviation for inflating left and right airbags to a certain limit, hence car body would be balanced.

2) Call condition: The height deviation of left and right airbag is beyond error value, that is, $\varepsilon = |H_l - H_r| > \gamma$.

Terminating condition: the height deviation of left and right airbag is lower than or equal to error value γ, that is, $\varepsilon = |H_l - H_r| \le \gamma$.

3) Input signals: Speed signals, height sensor signals, module switch signals.

4) Output signals: The control signals from solenoid coils 6.1, 6.2, 6.3.

Besides the height deviation comparison of both airbags, error adjustment module would also judge vehicle situation and then choose target height, so two factors have to be taken into considerations when adjusting airbags, that is, Ⅰ, the difference between present airbag height and target height; Ⅱ, height deviation of both airbags. However, it has to be mentioned that the height deviation adjustment of both airbags is prior to target height adjustment and the error value γ can be calibrated by drivers themselves. No allowance for too small error value, otherwise, it may result to the frequent inflating and deflating airbags from solenoid valves.

4. Simulation Test

To verify the logic correctness of height control, a simulation test is conducted in Matlab/Simulink environment. Since error adjustment module is the basic module for height adjustment and the realization of all the other modules' adjustment functions are based on it, altogether three situations are specified to check work logic of error adjustment module.

1) The initial height is all lower than the target height of pre-control.

2) The initial height for one airbag is lower than target height while the other one's is above it.

3) The initial height is all above the target height of pre-control.

Take start control module for instance, the simulation test module in Matlab/Simulink can be shown as follows (Fig. 3).

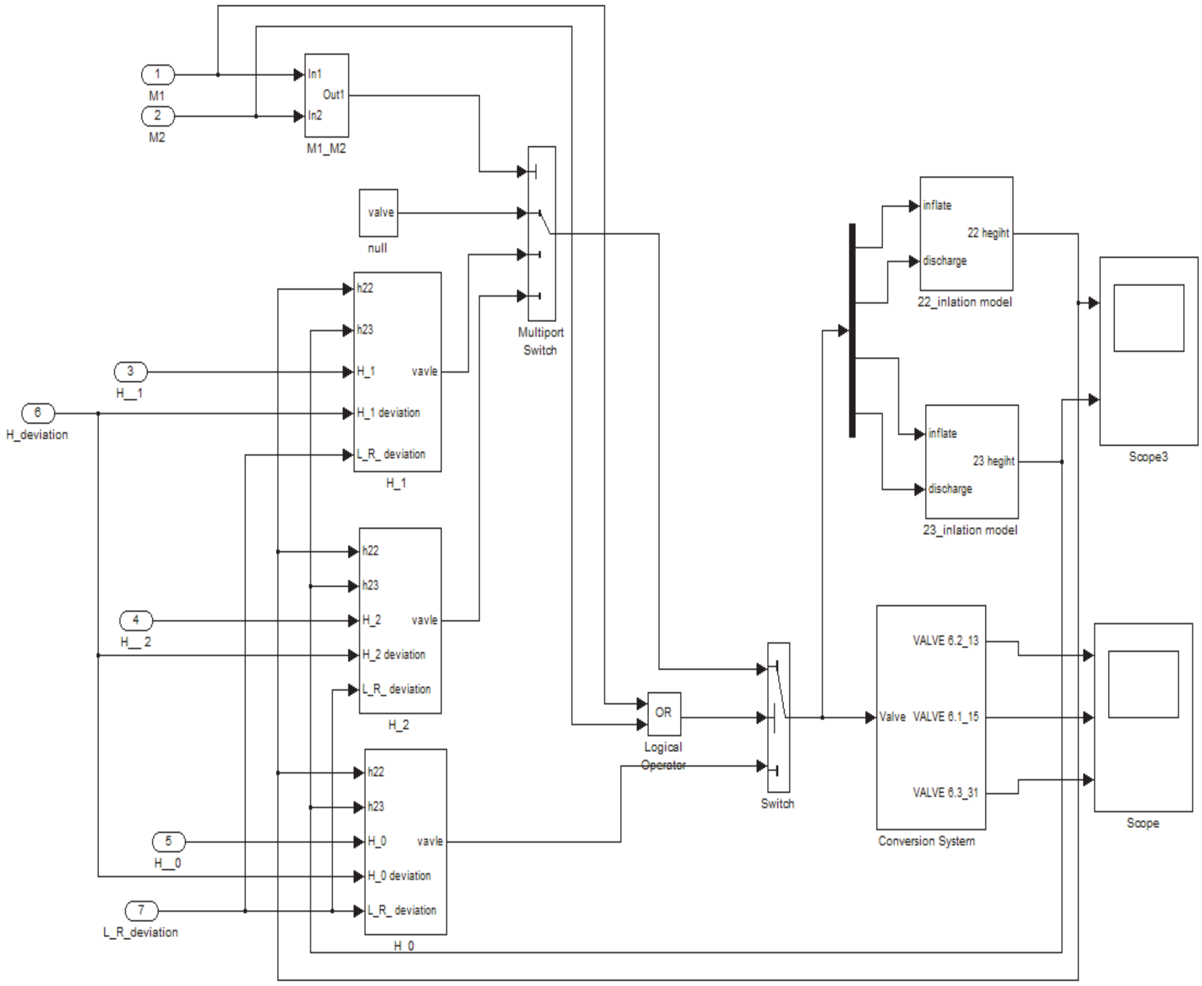

Fig. 3. Simulation Modal in Matlab/Simulink.

Parameters need to be calibrated in simulation modal have shown in Table 1.

Table 1. Parameters calibration for Start Module.

Name	Value (cm)
Normal height H_0	25
Special height H_1	15
Special height H_2	35
H_deviation	0.5
L_R_deviation	1

4.1. The Initial Height Are All Lower Than the Target Height of Pre-control

After the vehicle stalled for a certain time, the air from the pipe joints of airbags and solenoid valves would be leaking and thus making both airbags' height lower than normal height, at the same time different leakage for different airbags would make the height deviation of two airbags become much more obvious. Suppose No. 22 (left) airbag height is lower than that of No. 23 (right) airbag, and no manual adjustment signals detected after the vehicle started, at this time, the default height will be Normal height H0, then the strategy for height deviation adjustment is like this: inflate No. 22 airbag (keep No. 23 airbag in a pressure-holding state) until the height deviation of No. 22 and No. 23 airbag is lower than γ, at this time, system will inflate both airbags until they reach the normal height. The results of simulation test can be shown as in Fig. 4.

It is clear from Fig. 4 that at the beginning of the simulation test, the system will inflate No. 22 airbag since there is a large height deviation at the initial state of No. 22 and No. 23 airbags, 1.5 seconds exactly then, the deviation value will be less than 1cm for two airbags, at the time of which the system will inflate both airbags at the same time until 3.5 seconds later, two airbags will all reach the normal height and keep in a state of pressure holding. Therefore, it can be concluded that the working logic of solenoid valves is correct and the expected functions will be realized.

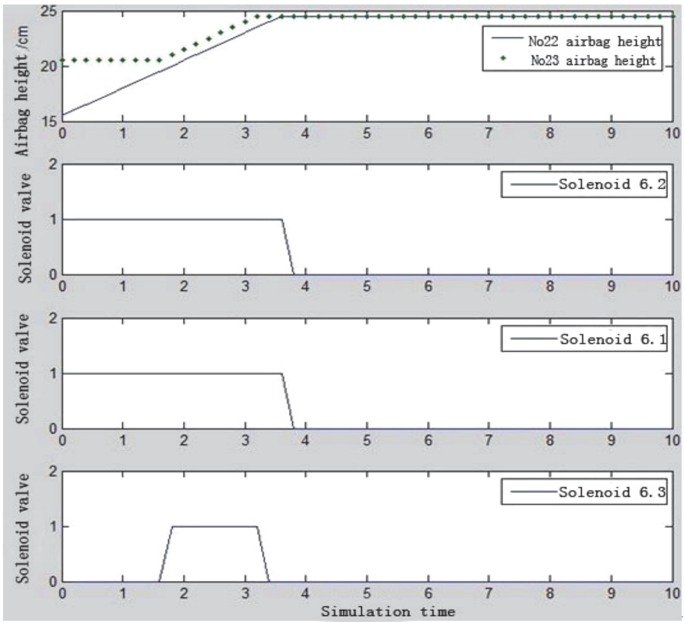

Fig. 4. Simulation Results: when two Airbags'height are lower than target height.

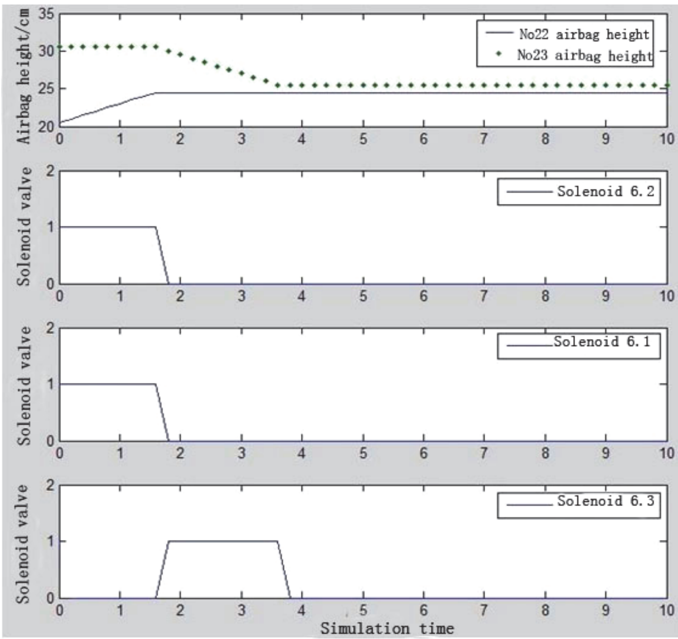

Fig. 5. The Simulation Results: when two Airbags'height are at the both sides of target height.

4.2. Two Airbags'height Are at the Both Sides of Target Height

When the vehicle is in an idling state and does some cargo loading, the loading unbalance will lead to the center of mass deviate and make the stress on the air spring of both sides different, thus, height deviation will occur. Similarly, suppose here No. 22 airbag height becomes lower than the normal range of normal height, and No. 23 airbag height becomes higher than normal range, then the strategy for height deviation adjustment is as follows: inflate No. 22 airbag, and No. 23 airbag is in a state of pressure holding. Not to deflate No. 23 airbag until No. 22 airbag is within the normal height range and not to terminate deflation until it is within normal range. The simulation test results of this part can be illustrated in Fig. 5.

It is clear to see from Fig. 5 that from the beginning of the simulation test to 1.5 seconds, No. 22 airbag is inflated, while No. 23 airbag is in pressure holding state. No. 23 airbag begins to deflate from 1.5 seconds to 3.5 seconds when No. 22 airbag is in pressure holding state; 3.5 seconds later, two airbags will keep the same height and therefore controlling demands for height deviation will be met successfully.

4.3. The Initial Height are All Above Target Height

When it is necessary to lower vehicle chassis height, a deflation of airbags is needed. However, if the initial height of two airbags is different and there is a large height deviation value, then the strategy is like this: deflate the airbag with a relative higher height and not to deflate both airbags until the higher airbag keeps the same height with the lower airbag's. Suppose No. 23 airbag height is higher than that of No. 22, the simulation results can be shown as in Fig. 6.

It is clear to see from Fig. 6 that the system will first deflate No. 23 airbag and meantime keeps No. 22 airbag in pressure. It will not deflate the two airbags until 1.5 seconds later the two airbags are in a same height. The deflating will continue until it has reached the expected height. Therefore, here it may be inferred that the solenoid control logic is quite right.

The above simulation test is based on start module, and since other modules' simulation test is quite similar with this, here no more details for others.

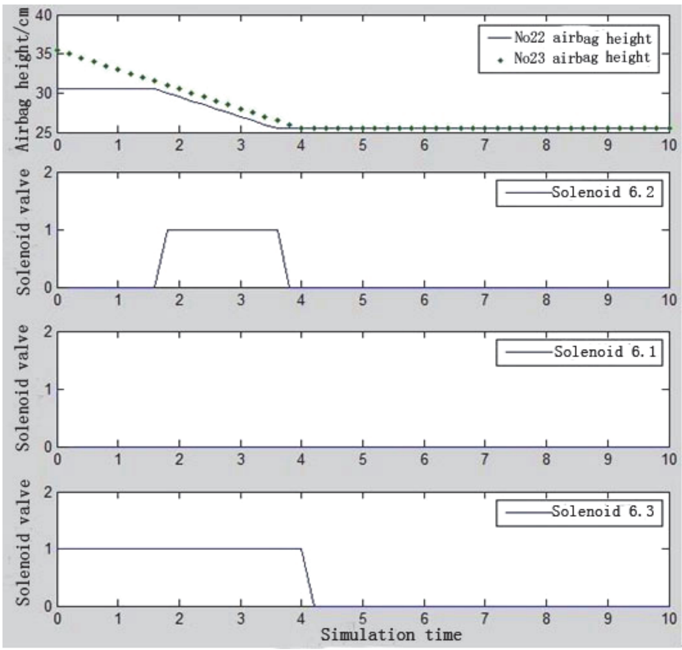

Fig. 6. The simulation results: when the initial height are all above the target height.

5. Conclusions

Based on modular design, this paper divides height control strategy for air suspension into start-control module, dynamic adjustment module, manual adjustment module and error adjustment module. Module selection switch decides the working state of above modules. Simulation tests in MATLAB/Simulink indicated that the air suspension height control strategy is featured by its mechanism simplicity, logical control accuracy, and debug convenience. What has been studied in present paper is the simplest uniaxial air suspension system, however, slight change on it will also make it plausible for biaxial air suspension system and the designing method and ideas can be used as a helpful reference for developing other forms of electronic control air suspension control systems.

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