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Modeling, Simulation and Body Height Adjustment Control of Full Car Laterally Interconnected Air Suspension System

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Abstract:- In this paper, the working principles, the dynamic performance, and the static characteristics of full car interconnected air suspension are investigated and verified using established real physical test benches and simulations. Also, the physical and mathematical models of the suspension are established to help study the vehicle's roll, pitch, bounce and other relevant motions. PID and Fuzzy controllers are built using matlab/simulink to simulate and control the body vertical height adjustment of the interconnected air suspension. Two two-dimensional fuzzy controllers are applied respectively to control the front and rear air springs. To improve height adjustment precision, a target height of 20 mm is used as input to the front controller; while the actual body height in front air spring is used as an input to the rear controller. The results of the simulation clearly demonstrate that compared with the open-loop switch control, PID and fuzzy controllers are found to effectively suppress the overshoot during the process of body height adjustment. Again, by setting the front wheels as the target height, the designed controllers quickly and accurately adjust body height to the target height and significantly stabilized and improved the performance of the system as compared to the open-loop switch control.

Keywords: - Full Car, Modeling, Simulation, Laterally Interconnected, Air Suspension.

I. INTRODUCTION

Interconnected suspension is a suspension system in which a displacement at one wheel station can produce forces at other wheel stations [1]. Unlike conventional suspensions, interconnected schemes, in theory, afford the designer complete control over the stiffness and damping of each suspension mode. Moreover, interconnected suspension can be classified in terms of the transfer media, including mechanically, hydraulically, pneumatically and hydro-pneumatically interconnection. Interconnected air suspension (IAS) is a new type of suspension with good vibration isolation and torsion eliminating performance. A vehicle equipped with air suspension can obtain lower natural frequency, the variation of body vibration frequency would be very small in case of load change, and the vehicle height could stay the same [2]. Air suspensions effectively reduce dynamic wheel load, thereby causing vehicle to obtain good performance of comfort, high performance of handling stability, driving safety, with little destruction to the road [3]. The air suspension has excellent controllability in its structure; it can easily regulate body height or automatically adjust suspension stiffness, damping, and so on. Moreso, it can significantly improve riding smoothness, hence, has been widely used in advanced car, sport utility vehicle (SUV), medium-sized car, senior car and heavy-duty truck [4]. Xu etal analyzed the dynamic characteristics of air suspension charging-discharging process by creating the Matlab/Simulink model, and researched the cause of “over-charging” or “over-discharging”, which could provide a foundation for the height control strategy of air suspension [5]. Zhao et al. globally linearized the nonlinear model of charging-discharging through the state feedback method, and a sliding mode controller designed based on the state feedback linearization theory, which was able to handle the nonlinear characters of the charging-discharging process [6].

The structure of interconnected air suspension was proposed by Higginbotham in 1961[7]. The IAS can be mainly classified into two forms. One is laterally interconnected air suspension, in which air springs on the same sides of different axles are connected. Laterally interconnected air suspension is a new type of suspension. It has great development potential because of the short interconnected pneumatic pipes and convenient locating properties, which can effectively improve the performance of vibration isolation and torsion elimination for passenger cars [8]. Wolf-Monheim etal integrated a laterally interconnected air springs simulation model into the 7-degree-of-freedom (DOF) vehicle model and studied the vibration isolation performance and rolling performance of the interconnected air suspension. Simulation results showed that the lateral interconnected air suspension could effectively reduce the acceleration of body roll angle and that the parameters of interconnection pipes have a great impact on the interconnecting effectiveness [9, 10]

With regard to longitudinal interconnection, Bhave studied the transfer characteristics of longitudinally interconnected air suspension based on a 2-DOF half vehicle model, and analyzed the influence of air spring volume ratio and pipe inner diameter on body pitching angle and the transfer characteristics of sprung mass acceleration, without considering the deformation of the vehicle body [11]. Kat and Schalk established a mathematical model for longitudinally interconnected air suspension based on a three-axle semitrailer and verified it through experiment [12]. Davis and Bunker conducted detailed research on the impact of a longitudinally interconnected suspension system on the ride comfort and road friendliness of heavy duty trucks [13-15]. Basically, air suspension system mainly consists of air spring systems, guide system, shock absorbers, stabilizer bar, thrust rod, cushion stopper and other components. Vehicle air spring system includes air springs, auxiliary chamber, height valves, pressure valves, dust filter, accumulator, connecting pipes and so on [16]. The rubber balloon of air spring is made of rubber/fabric structures, upper and bottom plate and the piston of air form a sealed space, which is full of compressed air to provide support reaction force. Automotive air suspension is actually air spring system [17]. More so, air suspension systems essentially comprise strong nonlinearity of rubber balloon, rubber shock absorber and other key components, and therefore making them complex machines [18]. According to existing technical documents, when making air suspension vehicle dynamics analysis, the general treatment of air springs as a set of linear springs while ignoring the impact of height valve, connecting tubes, the auxiliary chamber and other parts, which make the multi-body dynamics model of vehicle system could not reflect the true influence of nonlinear parameters on vehicle dynamics, thus it would lead to deviations of dynamics simulation analysis inevitably [19]. Due to the strong nonlinearity, parameter changes and other factors associated with air suspension, the conventional control algorithm is difficult to meet the increasing requirements of ride comfort and steering stability, and the control system is also more difficult to develop. Therefore, the establishment of "dynamics and control dynamics models" which can reflect the nonlinear air spring is the key of developing air suspension [20].

The purpose of this paper therefore, is to present a physical and mathematical model of full car interconnected air suspension system which could be used to analyze the suspension's dynamic performance and develop appropriate control strategies to control vehicle's roll, pitch, bounce and other relevant motions. Also, PID and Fuzzy controllers are built using Matlab/Simulink blocks to control essentially, the body height movement of the full car model. This is to hammer home the fact that, even though interconnected air suspensions are nonlinear, complex, difficult to control, and therefore requires ample time and expensively built experimental setups to simulate, they can be equally studied simply by using software simulations and achieve results close to that of costly built experimental setups.

II. LATERALLY INTERCONNECTED AIR SUSPENSION SYSTEM OVERVIEW

Laterally interconnected air suspension combines coaxial left and right air springs with pneumatic pipes, thereby allowing the gas between the interconnected air springs to exchange freely. Traditionally, the control of this suspension system is based on charging and discharging of air into and out of the air springs. Body height adjustment strategy is one of the main functions of air springs, where the system actively charges or discharges gas into or from air springs according to drivers intention and driving conditions, so that the air suspension can realize the adaptive adjustment of body height [21].

2.1 Working Principle and Dynamic Performance of Laterally Interconnected Air Suspension System

In order to examine the working principle and dynamic performance of an interconnected air suspension in this paper, a test bench of a vehicle equipped with interconnected air suspension is created, as shown in figure 2.1. The test bench is built based on MTS320-035 four-channel tire coupling road simulation test system, which can impose static or dynamic excitations on all full car four wheels.

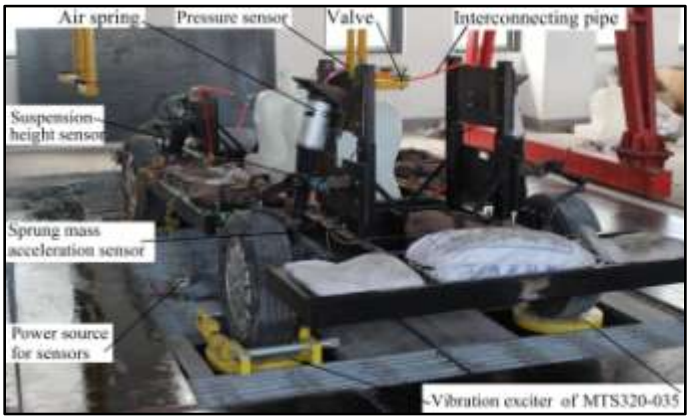

Fig 2.1: Test Bench of Interconnected Air Suspension System

Three kinds of sensors are utilized in this test: four air pressure sensors, four suspension height sensors and eight single-axis accelerator sensors. The Air pressure sensors are linked with air suspension by pneumatic pipes. The air spring height sensors are placed on some extra holders. Each of these holders has two knuckle arms and the height of the suspension can be ascertained by measuring the angle between them. Four single-axis accelerator sensors are placed on the vehicle body, corresponding to four suspensions, to measure sprung mass acceleration, while the other four are placed on the inner side of four wheels to measure the acceleration of unsprung mass. Measured signals are collected by the LMS SCADAS Mobile SCR05 data acquisition instrument. A diagram of the test bench layout is shown in Fig. 2.2. The parameters of the model car used in this bench test are listed in table 1.

The air springs and absorbers used in the test come from Bens S320, and its static characteristics are tested by INSTRON 8800 Single-channel Electro-hydraulic Servo Test System, as pictured in fig. 2.3a. Different displacement excitations are imposed on the bottom of the air spring by INSTRON 8800 while the top of the air spring is fixed on a platform. The air pressure of the spring, P, and the spring force, F, are measured by sensors and the effective area (the ratio of F to P) characteristics of the air springs are measured and illustrated in fig. 2.3b.

2.2. Static Test Study of Lateral Interconnected Air Suspension

In order to study the impact of lateral interconnecting on vehicle roll stiffness quantitatively, a static test is designed as shown in fig. (2.4-a). While keeping the total weight of the sprung mass unchanged, the load on the car frame (sand bags) from the left side of the vehicle body is moved to the right side gradually. Therefore, the rolling moment caused by uneven load increases gradually, leading to the increasing of vehicle body roll angle. Fig. (2.4- b) depicts the body roll angle with different roll moment. ('initial roll moment' in this paper means the rolling moment caused by uneven load. It does not include roll moment due to the sprung mass migration caused by body roll, which is substantially equivalent to roll moment due to centrifugal force of cornering). As can be seen from Fig. (2.4-b), compared with non-interconnected air suspension, lateral interconnection will decrease air suspension roll stiffness significantly, which means it will deteriorate the body rolling movement in turning condition and positively affect the control stability of the vehicle.

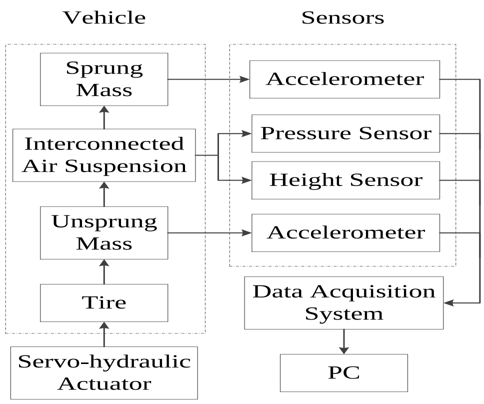

Fig. 2.2: Test bench of interconnected air suspension system

Fig. (2.3-a): Test bench for measuring static characteristics of air spring

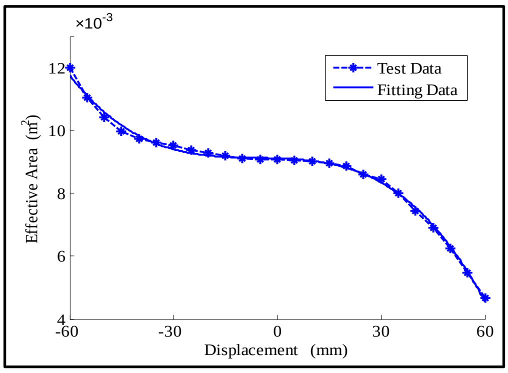

Fig. (2.3-b): Effective area characteristic of air spring

Fig. (2.4-a): Static test bench

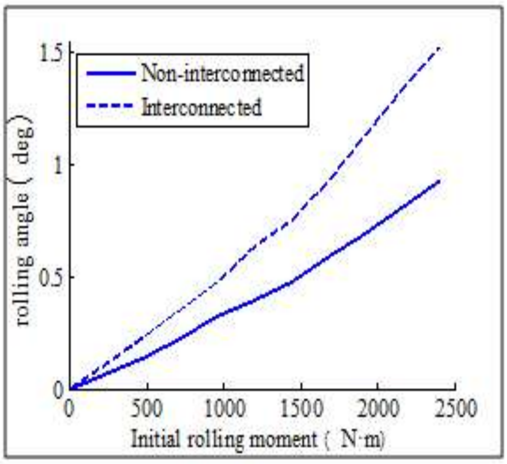

Fig. (2.4-b): Effect of interconnecting on air suspension

III. PHYSICAL MODELING OF INTERCONNECTED AIR SUSPENSION SYSTEM

In order to set up control dynamics models for specific vehicle physical models, a test or simulation is required to be conducted for prototypes in different driving conditions and different interconnecting states to judge which interconnecting state is more suitable for the current driving condition according to the mean and variance values of vehicle's roll angle. In this text, a simulation method is set up using the parameters of a certain prototype. The parameter values of this prototype are as given in table1.

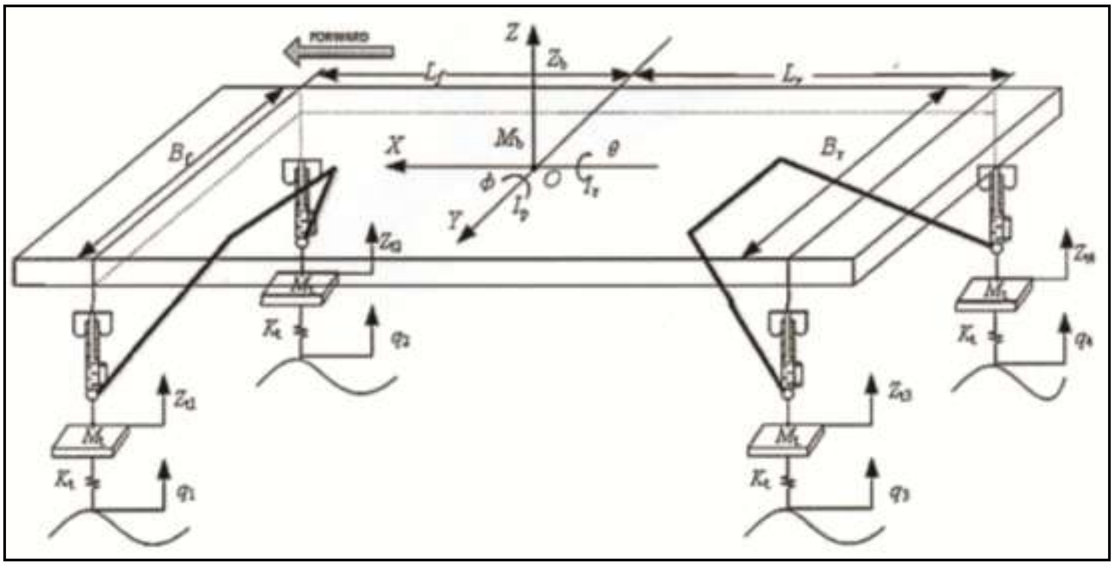

Fig. 3.1: Full Car Physical Model with IAS

3.1 Mathematical Modeling of Laterally Interconnected Air Suspension System

In the current research field of interconnected air suspension, a model which considers roll, pitch and vertical displacement of sprung mass, and four vertical displacements of unsprung mass as 7 degrees of freedom, is usually used as vertical dynamic simulation model. To simulate the actual driving conditions more approximately, 7-DOF vehicle model is established as shown in fig. 3.1. The derived governing equations for this full car interconnected air suspension model are thus:

The heave, roll, and pitch dynamics of the vehicle are as shown in equations 1, 2, and 3, respectively [22, 23].

$M_b \ddot{Z}_b = F_1 + F_2 + F_3 + F_4 - M_b g$ (1)

$I_r\ddot{\theta} = B_f(F_1 - F_2)/2 + B_r(F_3 - F_4)/2$ (2)

$I_p\ddot{\phi} = (F_3 + F_4)L_r - (F_1 + F_2)L_f$ (3)

The dynamics of each wheel are as illustrated in equations 4, 5, 6, and 7 respectively:

$M_t\ddot{Z}_{t1} = K_t(q_1 - z_{t1}) - F_1 + M_b \cdot g \cdot L_r / (2(L_f + L_r))$ (4)

$M_t\ddot{Z}_{t2} = K_t(q_2 - z_{t2}) - F_2 + M_b \cdot g \cdot L_r / (2(L_f + L_r))$ (5)

$M_t\ddot{Z}_{t3} = K_t(q_3 - z_{t3}) - F_3 + M_b \cdot g \cdot L_f / (2(L_f + L_r))$ (6)

$M_t\ddot{Z}_{t4} = K_t(q_4 - z_{t4}) - F_4 + M_b \cdot g \cdot L_f / (2(L_f + L_r))$ (7)

In which,

$F_1 = k \cdot f_{d1} + c \cdot \dot{f}_{d1}$ (8)

$F_2 = k \cdot f_{d2} + c \cdot \dot{f}_{d2}$ (9)

$F_3 = k \cdot f_{d3} + c \cdot \dot{f}_{d3}$ (10)

$F_4 = k \cdot f_{d4} + c \cdot \dot{f}_{d4}$ (11)

The suspension travel at each wheel is depicted in equations 12, 13, 14, and 15 respectively:

$f_{d1} = z_{t1} - (z_b - L_f\theta + \phi \cdot B_f/2)$ (12)

$f_{d2} = z_{t2} - (z_b - L_f\theta - \phi \cdot B_f/2)$ (13)

$f_{d3} = z_{t3} - (z_b + L_r\theta + \phi \cdot B_r/2)$ (14)

$f_{d4} = z_{t4} - (z_b + L_r\theta - \phi \cdot B_r/2)$ (15)

If the Anti-roll bar effects are factored into the equations, then equations 8-11 are rewritten as:

$F_1 = k \cdot f_{d1} + c \cdot \dot{f}_{d1} - k_{\theta gf} \cdot (f_{d1} - f_{d2})/B_f^2$ (16)

$F_2 = k \cdot f_{d2} + c \cdot \dot{f}_{d2} + k_{\theta gf} \cdot (f_{d1} - f_{d2})/B_f^2$ (17)

$F_3 = k \cdot f_{d3} + c \cdot \dot{f}_{d3} - k_{\theta gr} \cdot (f_{d3} - f_{d4})/B_r^2$ (18)

$F_4 = k \cdot f_{d4} + c \cdot \dot{f}_{d4} + k_{\theta gr} \cdot (f_{d3} - f_{d4})/B_r^2$ (19)

Table1 depicts a clarification to the various symbols, letters, variables (unknown values), constants (known values) and the input parameters of the model equations.

Now, considering the air spring as an adiabatic system, the internal gas motion equation is given as:

$$p_i\left(\frac{V_i}{m_i}\right)^{\kappa} = \text{const} \qquad (i = 1, 2, 3, 4) \tag{20}$$

where, V_i (i=1, 2, 3, 4) are the volumes of each air spring; m_i are the masses of gas inside each air spring; P_i is the internal absolute pressure of air springs; κ is the isentropic exponent, which equals 1.4 for air. Based on the principle of one dimension entropic flow, mass flow rate of air through a vehicle interconnecting suspension system pipes can be described as:

$$q_m=\begin{cases}A_tP_{up}\sqrt{\dfrac{1}{RT_{up}}\dfrac{2\kappa}{\kappa-1}\left[\left(\dfrac{P_{dn}}{P_{up}}\right)^{\frac{2}{\kappa}}-\left(\dfrac{P_{dn}}{P_{up}}\right)^{\frac{\kappa+1}{\kappa}}\right]} & \dfrac{P_{dn}}{P_{up}}\geq 0.528\\ A_tP_{up}\left(\dfrac{2}{\kappa+1}\right)^{\frac{1}{\kappa-1}}\sqrt{\dfrac{1}{RT_{up}}\dfrac{2\kappa}{\kappa+1}} & \dfrac{P_{dn}}{P_{up}}<0.528\end{cases} \tag{21}$$

where, P_{up} is the gas pressure of upstream; P_{dn} is the gas pressure of downstream; T_{up} is the gas temperature of upstream; A_t is the effective cross sectional area of the orifice. Besides throttling effect, there is also a time-lag effect between two ends of the pneumatic pipe and R is the gas constant. Edmond and Yildirim (2000) proposed a way to measure the relationship between the flow rates of pneumatic pipe end which is given as:

$$\dot{m}(L,t)=\begin{cases}0 & t\leq L/c\\ e^{-\frac{R_tRT_{dn}}{2P_{dn}}\frac{L}{c}}q_m\left(0,t-\dfrac{L}{c}\right) & t>L/c\end{cases} \tag{22}$$

in which,

$$R_t=\frac{32\mu}{d^2} \tag{23}$$

where, L is the length of the pipe, T_{dn} is the gas temperature of downstream, R_t is the flow-resistance characteristic coefficient of the pneumatic pipe; c is the velocity of sound, which is 346 m/s when the temperature is 25°C; μ is the viscosity coefficient of air; d is the diameter of the pipe.

The roll characteristic of interconnected air suspension obtained by the simulation model is pictured in Fig. 3.2. As can be seen, the simulation results compared favorably with the static test results obtained in fig. (2.4-b). This goes to demonstrate that the 7-DOF established simulation model is of high accuracy and can be used as the basis of establishing an interconnecting state control strategy or rule.

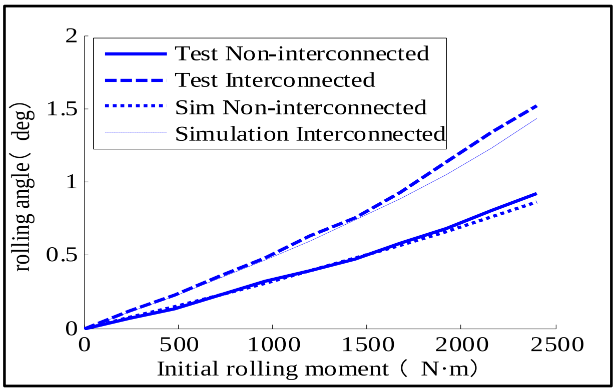

Fig. 3.2: Comparison of Rolling Characteristic Gained by Simulation and Test Bench

IV. BODY HEIGHT ADJUSTMENT PRINCIPLE OF LATERALLY INTERCONNECTED AIR SUSPENSION

Laterally interconnected air suspension combines coaxial left and right air springs with pneumatic pipes, allowing gas between interconnected air springs to exchange freely. The structure of body height adjustment for laterally interconnected air suspension is shown in Fig. 4.1. In this structure, the charging-discharging system of controlling the interconnected air springs simultaneously is based on the traditional charging-discharging system. However, the charging-discharging solenoid valves which control the corresponding valves required to adjust body height are installed in different lines. Again, in this structure, the vehicle state is judged by an Electronic Control Unit (ECU) according to the input signals. Two pressure sensors are respectively placed in the front right air spring and rear right air spring to monitor the pressure changes of air springs in real time, and four height sensors are respectively placed in four air springs to monitor height variations.

When the vehicle state has requirements for body height, the corresponding solenoid valves are controlled by the control algorithm written in advance in the ECU to realize the process of body height adjustment. In Fig. 4.1, 1 and 2 are charging solenoid valves, 3 and 4 are discharging solenoid valves. The high pressure gas stored in the reservoir tank is supply to the air springs, and when the ECU monitors that the pressure of the reservoir tank is insufficient, then the air compressor and solenoid valve 5 will turn on to pump gas from atmosphere to reservoir tank [25, 26].

Parameter	**Symbol**	**Values**	**Unit**
Constants (known parameters)			
Body mass	M_b	2039	Kg
Wheel mass	M_t	53.64	Kg
X axis rotational inertia	I_r	586	kg·m^2
Y axis rotational inertia	I_p	3492	kg·m^2
Wheel track	T_w	1.515	m
Vertical Tire stiffness	K_t	250	kN/m
Stiffness of air spring	K	12	kN/m
Distance from centroid to rear axle	L_r	1.321	m
Distance from centroid to front axle	L_f	1.417	m
Width of front side & rear side	B_f & B_r	1.515	m
Original volume of air spring	V_o	2.02x10^{-3}	m^3
Initial pressure of Air spring	P_o	0.65	MPa
Damping coefficient in compression travel	C_c	1800	N·s/m
Damping coefficient in stretch travel	C_s	3500	N·s/m
Inner diameter of interconnected pipe	D	0.012	m
Length of laterally interconnected pipe	L	1.05	m
Length of longitudinally interconnecting pipe	L	3.25	m
Acceleration of gravity	G	9.81	m/s^2
Roll stiffness of front anti-roll bars	$k_{\phi bf}$	600	N·m/ deg
Roll stiffness of rear anti-roll bars	$k_{\phi br}$	400	N·m/ deg
Equivalent thickness of vehicle body	S	0.075	m
Torsional rigidity of vehicle body	K_{tr}	6.37 x 10^4	N·m/°
State Variables (unknown parameters)			
Body roll angle (with respect to the x-axis)	Θ	-	Rad
Body pitch angle (with respect to the y-axis)	ϕ	-	Rad
Vertical Displacements of the wheels	z_{ti} (i = 1, 2, 3, 4)	-	m
Vertical Displacement of the body centroid	z_b	-	m
Suspension Force of four suspensions	F_i (i = 1, 2, 3, 4)	-	N
Suspension Displacement of four suspensions	f_{di} (i=1, 2, 3, 4)	-	m
Inputs (Road excitation)			
Road vertical excitations on the four wheels	q_i (i = 1, 2, 3, 4)	-	m

Table1: Parameters for full car interconnected air suspension modeling and simulation

V. BODY VERTICAL HEIGHT CONTROL USING FUZZY AND PID CONTROLLERS

5.1 Fuzzy Controller Design

The front and rear coaxial interconnected air springs are respectively unified as the front air spring and the rear air spring, and their height changes are the average value of interconnected air springs height changes. Due to the uneven load distribution of the front and rear air springs, the delay effect of pneumatic pipes are different, and the mutual influence of mass flow, which would lead to the height adjustment of the front spring and rear spring out of synchronization and body posture in the process of adjustment would be seriously deteriorated. Therefore, body height adjustment tracking strategy specific for laterally interconnected air suspension is established. Two two-dimensional fuzzy controllers are applied respectively to control the front and rear air springs. To ease the phenomenon of body posture deterioration during the body height adjusting, the input of front air springs controller is determined by the difference in the actual height and target height, while the input of rear air spring controller is determined by the actual height of front air spring. Fig. 5.1 depicts fuzzy control of height adjustment for whole car. In Fig. 5.1, the input is always a numerical value and must be fuzzified. The fuzzification of the input becomes a membership function to be evaluated. The output should be transformed into the precise value q_m.

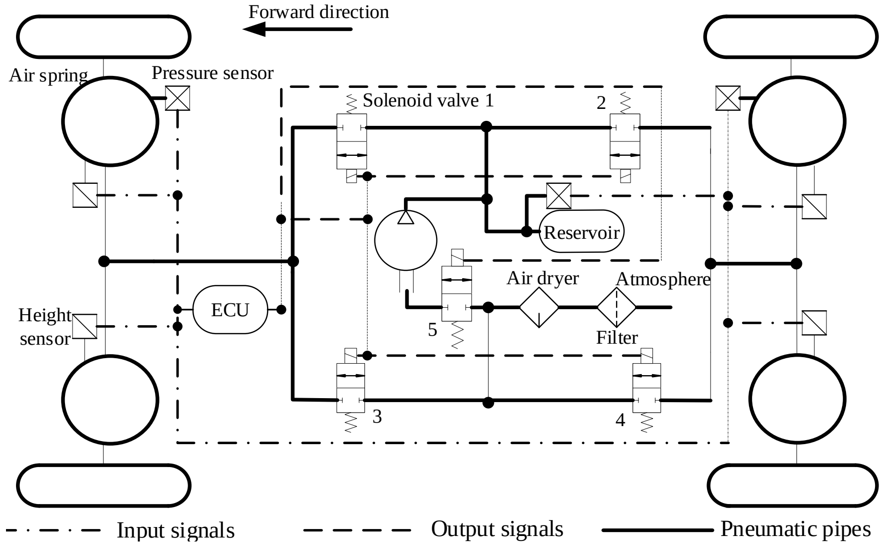

Fig. 4.1: The structure of body height adjustment for lateral interconnected air suspension system

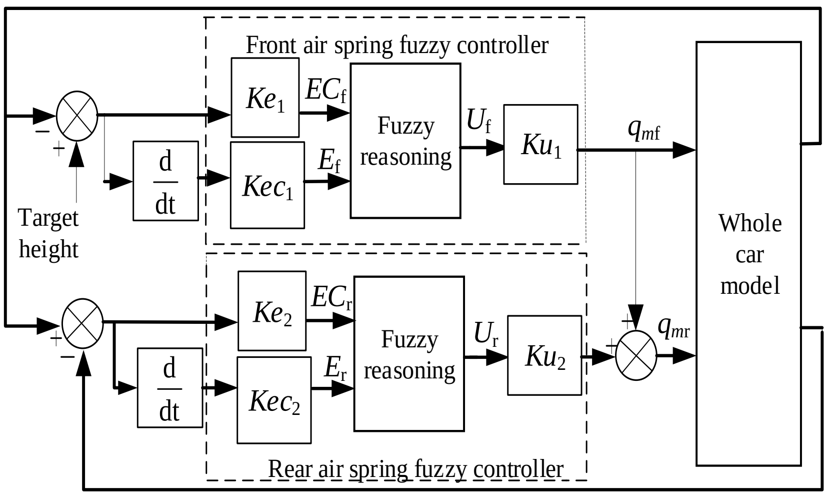

Fig.5.1: Fuzzy control of height adjustment for whole car

5.2 Front Air Spring Fuzzy Controller Design

The basic domain of inputs: height deviation (E_f), height deviation speed between the actual body height and the target height (EC_f); and outputs (U_f) as well as their fuzzy domains respectively in the front air spring is as illustrated in table2. It must be noted that, to ensure accuracy, the actual height in front air spring is used as the reference for the adjustment of the rear air spring.

In this work, the fuzzy logic controller used for the front air spring controller design has six fuzzy subsets: {NB, NM, NS, Z, PS, PM, PB} and membership functions are trimf. Moreover, in order to achieve precise adjusting, the basic principle according to work characteristics of the system is set as: the output mass flow is large as deviation is large, reducing the adjustment time, the mass flow is small as deviation is small, ensuring accuracy. Hence, Fuzzy control rule of front air spring based on the fuzzy subset is as illustrated in table 3.

Parameter type	Basic Domain range	Fuzzy Domain
Inputs: 1. E_f 2. EC_f	 [-0.02, 0.02] m [-0.01, 0.01] m/s	 [-6,6] [-5,5]
Output: U_f	[-1.2 x 10^{-8}, 1.2 x 10^{-8}] m^3/s	[-6,6]

Table2: Fuzzy parameters for front controller design

U_f \ EC_f / E_f	NB	NM	NS	Z	PS	PM	PB
NB	NB	NB	NB	NM	NS	Z	Z
NM	NB	NB	NM	NS	NS	Z	Z
NS	NB	NM	NS	Z	Z	PS	PS
Z	NM	NS	NS	Z	Z	PS	PM
PS	NS	NS	Z	Z	PS	PM	PM
PM	Z	Z	PS	PS	PM	PM	PB
PB	Z	Z	PS	PM	PB	PB	PB

Table3: Fuzzy Control Rule of Front Air Spring

5.3 Rear Air Spring Fuzzy Controller Design

For the rear air spring controller design, the basic domain of inputs: height deviation (E_r), height deviation speed between the actual body height and the target height (EC_r); and outputs (U_r) as well as their fuzzy domains respectively in the front air spring is as illustrated in table4. The Fuzzy control rules of rear air spring are as depicted on table5.

Parameter type	Basic Domain range	Fuzzy Domain
Inputs: 1. E_r 2. EC_r	 [-0.001, 0.001] m [-0.015, 0.015] m/s	 [-5,5] [-5,5]
Output: U_r	[-1.2 x 10^{-8}, 1.2 x 10^{-8}] m^3/s	[-6,6]

Table4: Fuzzy parameters for rear controller design

5.4 The Method of Pulse Width Modulation (PWM)

ON-OFF Solenoid valve can only switch discretely between open and close to make mass flow adjustable. Therefore, Pulse Width Modulation (PWM) is adopted, which is used to transform the size of mass flow into the corresponding PWM duty cycle. Dead zone is included in solenoid valve static characteristics, that is, when output of the controller is less than a certain value, the solenoid valve fails to work as switch. Meanwhile, the height dead zone will be set, and when height deviation is located within the height range of dead zone, body height adjustment will be stopped. Height dead zone refers to the height zone where the input signal is changed and output signal is unchanged. It is set so that, when body height adjustment is over, deviation between actual height and target height within 2% can be deemed to meet the control requirements. "Mamdani" is used as body height fuzzy control system, "max-min" is used for reasoning, and Gravity Method is used for defuzzification.

Ur / ECr / Er	NB	NM	Z	PM	PB
NB	NB	NB	NB	NM	Z
NM	NB	NB	NM	NM	Z
Z	NM	NM	Z	PM	PM
PM	Z	PM	PM	PB	PB
PB	Z	PM	PB	PB	PB

Table5: Fuzzy control rules of rear air spring

The abbreviation used in Table3 and 5 correspond to:

- **NB**….. Negative Big
- **NM**…. Negative Medium
- **NS**….. Negative Small
- **Z**…….. Zero
- **PS**….. Positive Small
- **PM**…..Positive Medium
- **PB**…. Positive Big

VI. SIMULATION AND CONTROL OF BODY HEIGHT ADJUSTMENT IN MATLAB/SIMULINK

In order to control and stabilize the vertical body height of the laterally interconnected air suspension full car vehicle model shown in fig.3.1, Fuzzy controller and Proportional Integral Derivative (PID) controller are established based on the charging and discharging processes of the air springs using Matlab simulink. Here, the conventional PID controller, Fuzzy controller and Open-loop switches are established concurrently in order to ascertain and verify the performance of the control system. Moreover, Ziegler-Nicholas (Z-N) method [27] is used to obtain the parameters for the PID controller where Kp=11, Ki=0.2, Kd =1, are values used for the vehicle height lifting process; whiles Kp=30, Ki=1, Kd=6 are values used for the vehicle height lowering process. Again, body height changes in the front air springs are adapted as the research object. The body height adjustment has three switch modes: “High Mode”, Normal Mode” and “Low Mode”. However, in this study, body height adjustments between normal and high mode switches are adapted. Simulation time is 10 seconds, and simulation step is 0.01. For the Fuzzy controller, the vehicle height simulation system is as shown in fig. 6.1. The major parameters of the vehicle body height adjustment system used in the Matlab simulation is depicted in table 1.

6.1 Simulation Results and Discussion

The Matlab/simulink simulation results for the body height adjustment for the lifting/rising procedure is pictured in fig. (6.2-a), whiles that of the body lowering procedure is depicted in fig. (6.2-b). As illustrated in the fig. (6.2-a) and fig. (6.2-b), significant overshoot exist in the adjustment processes of the open-loop switching control, which seriously affect adjustment accuracy. However, compared with the open-loop switch control, the PID and fuzzy controllers are found to effectively suppress the overshoot during the process of body height adjustment. Again, by setting the front wheels as the target height, the designed PID and Fuzzy controllers quickly and accurately adjusted body height to the target height of 20 mm and significantly stabilized and improved the performance of the system as compared to the open-loop switch control. Also, in this work, the simulation results clearly indicate that the fuzzy controller adjust the body height to the target height quickly and accurately than the PID controller.

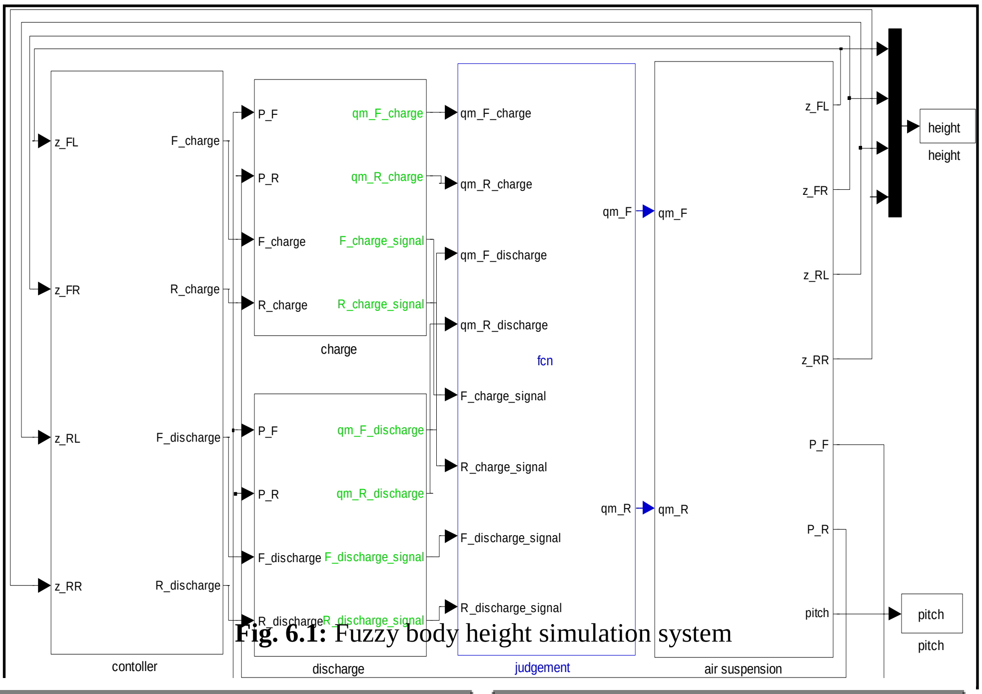

Fig. 6.1: Fuzzy body height simulation system

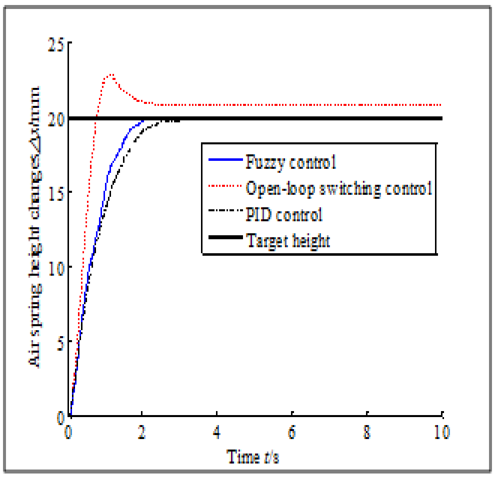

Fig. (6.2-a): the rising of body height

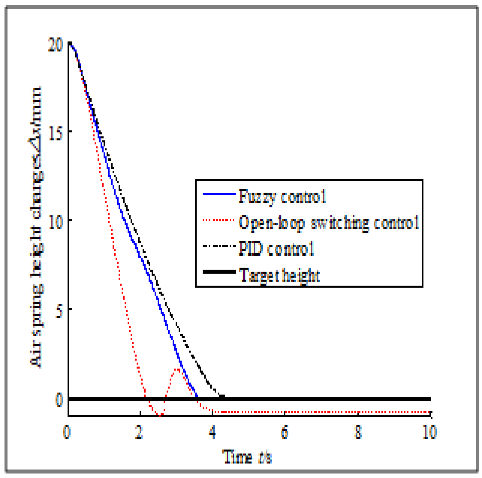

Fig. (6.2-b): the lowering of body height

VII. CONCLUSION

Vehicle dynamics analysis and controls in all respects requires that appropriate physical and mathematical models be established, and particularly simulated, tested and verified using well established real bench tests and/or computer simulations. Hence, in this work, computer simulations are done using mathlab/simulink to control the body height adjustment of the full car interconnected air suspension system. Indeed, computer simulations can serve as an indispensable tool to simulate and control the relevant motions of a complex suspension system such as the interconnected air suspension and achieve results close to that of expensively built experimental setups. Cost and time could also be significantly minimized in this regard.

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