Evaluation of Influence of Motorized Wheels on Contact Force and Comfort for Electric Vehicle

JIN Li-qiang,
State key laboratory of automotive simulation, Jilin University, Chanchun, China
e-mail: jinlq@jlu.edu.cn

SONG Chuan-xue
State key laboratory of automotive simulation, Jilin University, Chanchun, China
e-mail: songchx@126.com

WANG Qing-nian,
State key laboratory of automotive simulation, Jilin University, Chanchun, China
e-mail: wqn@jlu.edu.cn

Abstract*—Volatile oil prices and increased environmental sensitivity together with political concerns have moved the attention of governments, automobile manufacturers and customers to alternative power trains. From the actual point of view the most promising concepts for future passenger cars are based on the conversion of electrical into mechanical energy. In-wheel motors are an interesting concept towards vehicle electrification that provides also high potentials to improve vehicle dynamics and handling. Nevertheless in-wheel motors increase the unsprung mass worsening vehicle comfort and safety. All kinds of motorized-wheel structures are analyzed. For the unitary motorized wheel, since increasing the unsprung mass of vehicle, it adds adverse effects on the vehicle road holding performance and vehicle comfortableness. To decrease the adverse effect for unsprung mass increasing, a method by attaching the motor in the wheel through springs and dampers of exclusive use is brought out. It is verified that the vibration of EV with suspended-motor motorized-wheel is better than the EV with detached-motorized wheel. For high cost of suspended in-wheel motor, The effect of increasing of unsprung mass by using integral motor is analyzed by simulation with whole vehicle model. The more unsprung mass of integral motor deteriorates the vehicle comfort and vibration performance at low excitation frequency of road. But it is improved by using integral motor at higher excitation frequency of road, while unsprung mass is increased by using integral motor. The fluctuation amplitude of vibration at high frequency is much more big than at low frequency. In this view, the conclusion that in-wheel motor integrated into wheels is acceptable structural concept for electric vehicle with motorized wheels with lower cost than suspended in-wheel motor is achieved

***Index Terms*— Electric Vehicle; motorized wheels; road holding performance**

I. INTRODUCTION

Based on the increasing environment and air pollution, Electric Vehicle has become the new technique trend for its low emission and energy saving characteristics. However, recent EV is still uncompetitive in performance and cost compared with conventional vehicle. Application of motorized wheel in EV is a good way to downsize the cost and improve the vehicle performance[1,2]. In motorized wheels driving system, mechanical transmission is eliminated through integrated design of motor and wheel. Vehicles with this system could achieve the advantages that: (1) Vehicle mass would be downsized. Conventional transmission system takes a big part of vehicle mass, while the motor and controller are comparatively much smaller. (2) Cost would be downsized. The R&D cost of high performance vehicle is considerable. Motorized wheel driving system takes the utility of power electronics for the power transmission which is based on the wire transmit and control structure. This kind of transmission, compared with the conventional mechanical transmission, is much easier to be modulized, cheaper for the R&D cost and simpler in vehicle design. (3) Vehicle comfortableness would be improved. Because the mechanical transmission is eliminated, there is no noise and vibration generated. Chassis height could be reduced to provide more passenger room. (4) Vehicle safety would be improved. The driving torque could be controlled independently in motorized wheel system, so it is much flexible and comfortable to realize the vehicle dynamic control including ABS, TCS and VSC solely by controlling the driving motor[2,3]. Because the motor has a faster response than mechanical transmission, vehicle with motorized wheel has better brake, dynamic and safety[4,5,6].

In this paper, based on the vertical vibration model built, the effects of structure of motorized wheels were analyzed on the comfort and road holding performance of Electric Vehicles, and then vehicle comfort and vibration performance is analyzed by simulation using whole vehicle model comparing integral motor structure with split motor structure. The solutions is brought out to enhance the comfort and road holding performance..

doi:10.4304/jcp.6.3.497-505

I. STRUCTURE ANALYSIS

Fig.1~3 show the typical structure of motorized wheels. Fig.1 is the structure of dualmotor. It is modified from an induction motor or a synchronous motor. When vehicle running straight forward, the flux generated lies along the axial direction. Because the stator flux would be divided into two equal parts, which goes through the rotors on each side, torque and speed of one rotor would be the same as that of the other. When vehicle turning, under the same voltage frequency, the speed of outer wheel connected with its rotor (defined as rotor 1) will increase. As it gets closer to the synchronous speed, the current in rotor1 will decrease for the reactance; the slip frequency of rotor2 will increase, which will lead to the increasing of rotor winding’s current and reactance. Thus, more flux flow into rotor1, making torque in rotor2 decrease. However, the torque delivery will cause a oversteering under high speed turning. This motor structure also takes much place in the middle, which will contribute to a bad comfort and trafficability[6,7].

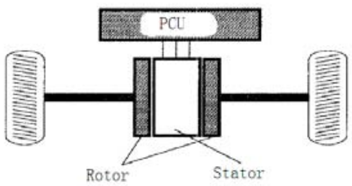
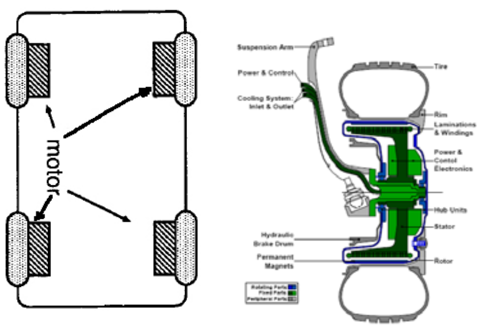


Figure 1. Motorized wheel with dualmotor



(a) (b)

Figure 2. Motorized Wheel with Integrated Motor

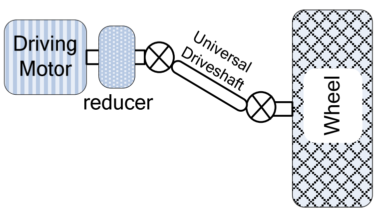


Figure 3. Motorized Wheel Connected with Universal Driveshaft

Fig.2(b) shows a motorized wheel integrated with a motor in the wheel. Fig.2(a) is the 4WD vehicle powered by integrated-motorized wheels[8]. This configuration requires less mounting place, which is the ideal one for layout. The motor is designed into an in-wheel motor that can be easily placed in the wheel hub. However, this structure has some certain disadvantages: It is hard to introduce a speed reducer, so the motor should provide adequate torque to drive the vehicle; Brake is hard to be installed in the wheel hub after motor is mounted; Meanwhile, the integrated structure will lead to a bad cooling, as a result of which, motor should have reliable performance allows to work under terrible conditions including high temperature and strong vibration. Moreover, adding in unsprung mass will deteriorate the comfortableness and road holding ability.

Fig.3 is the detached-motorized wheels, in which motor and speed reducer are connected with vehicle body. This kind of structure has smaller room for overall arrangement than that in Fig.2, but is much easier to realize the motor driving from little modification on the conventional vehicle. With this structure, motor could work under good conditions and provide more reliable performance without any amplification of un sprung mass.

III EFFECTS OF THE STRUCTURE OF MOTORIZED WHEEL ON VEHICLE PERFORMANCE

Structure in Fig.1 should be redesigned for the uncomfortable of independent control of wheel’s torque. It is just a kind of tentative structure that still has a long way to the real application. In the coming part, comparison and analyze would be taken on the comfortableness and road holding performance between detached-motorized wheels and integrated one.

A. Evaluation of comfortableness and road holding performance

It is very important to keep a good road holding performance of the tire so that it could provide adequate forces for vehicle controlling.

When the vehicle runs on the rough road, the increase of unsprung mass would delay the response. The amplitude of the vertical deformation of the tire and the distance between tire and road would increase, as a result of which the corresponding amplitude of road holding force and the vertical vehicle body acceleration transmitted from sprung mass would increase as well making the comfortableness deteriorate.

Lateral force of tire is nonlinear with the road holding force. Thus, the increase of amplitude holding force will result the decrease of lateral force[9], as is shown in Fig.4.

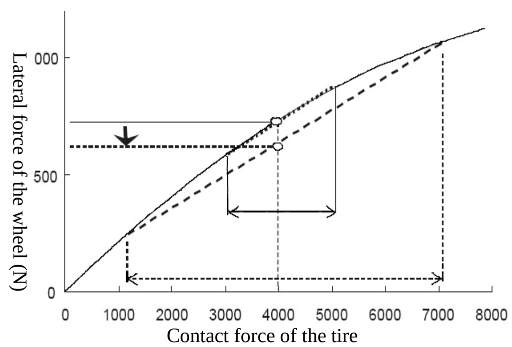


Figure 4. Relationship between the road holding force and the lateral force of the tire

When the fluctuation of road holding force decreases, the lateral force will increase and lead to a great improvement of the road holding performance[10].

B. Vibration model of vehicle with motorized wheel

Independent suspension is usually used in the vehicle driven by motorized wheels. Thus, the 2-degree vibration model in Fig.5 can completely express the vertical vibration of vehicle.

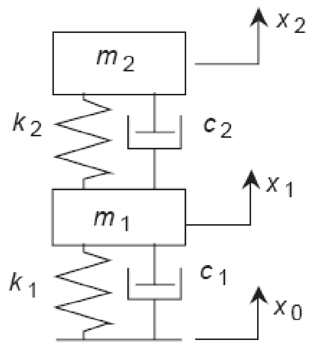


Figure 5. 1/4 vibration model of vehicle

In Figure5, x_0 is the road excitation; x_1 is the vibrating displacement of unsprung mass; x_2 is the vibrating displacement of sprung mass(vehicle body); k_1, c_1 are the vertical elastic constant and damping constant of the tire; k_2, c_2 are the elastic constant and damping constant of the suspension; m_1 is the unsprung mass of the vehicle. For the structure in Fig.2, unsprung mass includes the motor and the wheel, while for structure in Fig.3, it only includes the wheel; m_2 is the sprung mass of the vehicle. The vibration equations of the system are:

$$m_1 \ddot{x}_1 + F_n + F_t = 0$$

$$m_2 \ddot{x}_2 + c_2\left(\dot{x}_2 - \dot{x}_1\right) + k_2\left(x_2 - x_1\right) = 0$$

$$F_t = k_1\left(x_1 - x_0\right) + c_1\left(\dot{x}_1 - \dot{x}_0\right)$$

$$F_n = k_2\left(x_1 - x_2\right) + c_2\left(\dot{x}_1 - \dot{x}_2\right)$$

where: F_t —fluctuation of road holding force;

F_n —vehicle body's vibration inputs;

C. performance of road holding force and body comfort for vehicle driven by motorized wheels with high stiffness

Simulation model was built based on the vibration model mentioned before using Simulink software. Sine excitation signal was provided with the amplitude 5mm and frequency increasing in step. Simulation analysis of frequency of the road holding force, vehicle body acceleration and vehicle body vertical force fluctuation is fulfilled based on the split motor and integral motor. Comparative Results are shown in Fig.5 Fig.6 and Fig.7. Parameters of mass and damping coefficient used in simulation are shown in Table I. the suspension stiffness used in simulation is shown in table II. It can be seen that the stiffness of suspension and tire is higher than that used in car normally.

Table I. Simulation Parameter

Parameter	Detached-motorized Wheel	Integrated-motorized Wheel
m_1 (kg)	30	60
m_2 (kg)	360	330
c_1 (N/(m/s))	50	50
c_2 (N/(m/s))	1496	1496

Table II The stiffness of the suspension and tire as follows:

Parameter	Detached-motorized Wheel	Integrated-motorized Wheel
k_1 (N/m)	360000	360000
k_2 (N/m)	32000	32000

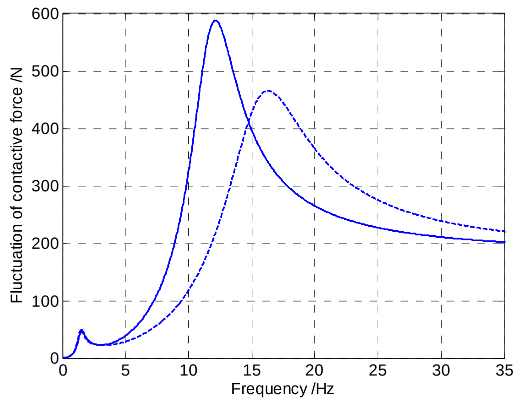


Figure 6. Comparison of the Amplitude of the road holding Force

The comparison of the road holding performance of Electric vehicle with split motor or integral motor is shown in Fig.5. The EV with split motor has less unsprung mass and there is less fluctuation of the road holding force than integral motor. The differential of the fluctuation amplitude is about 120N.

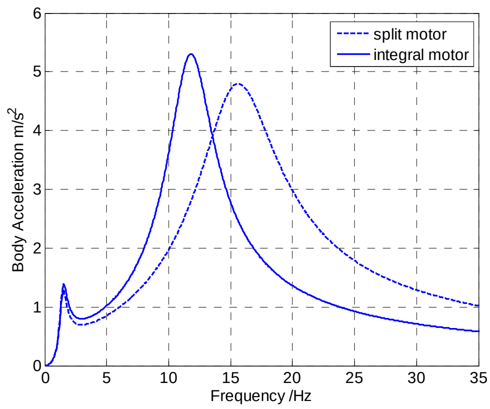


Figure 7. Comparison of the vehicle body Acceleration

The comparison of the vehicle body acceleration is shown in Fig.7. the vehicle with integral motor has higher acceleration than the one with split motor because of more unsprung mass at the resonant frequency（10-15Hz）. The resonant frequency of integral motor is lower than split motor. But the acceleration of EV with integral motor would be lower than split motor when the resonant frequency is exceeded.

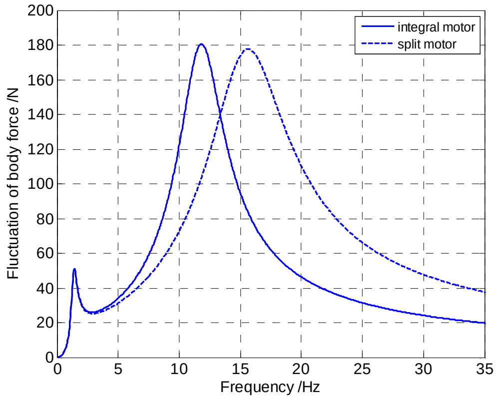


Figure 8. Comparison of Fluctuation of body vertical force

The comparison of fluctuation of body vertical force is shown in Fig.7. There're only small differences between the integral motor and split motor. But the resonant frequency of EV with integral motor is lower than split motor.

From figures above, integrated-motorized wheel has a larger unprung mass, so in the resonant frequency（10-15Hz）, the road holding force fluctuates much more than using detached-motorized wheel. The lateral force of tire decreases accordingly. Therefore, conclusions can be drawn that high speed stability of vehicles driven by integrated-motorized wheel is worse than that of vehicles driven by detached-motorized wheel. Vehicle body acceleration is the important critical reference for comfortableness. From Figure 3, comfortableness of EVs with detached-motorized wheel is better than that with integrated-motorized wheel below resonant frequency.

D. performance of road holding force and body comfort for vehicle driven by motorized wheels with low stiffness

Simulation is carried out by same model and same simulation parameter but the k_1 and k_2, it is shown in Tab.III

Table III The stiffness of the suspension and tire

Parameter	Detached-motorized Wheel	Integrated-motorized Wheel
k_1 (N/m)	180000	180000
k_2 (N/m)	16000	16000

For low stiffness of suspension and tire, The fluctuation amplitude of road holding force of EV is decreased remarkably comparing with high stiffness. As is shown in Fig.8, the EV with split motor has less fluctuation amplitude than that with integral motor. The differential between them is about 40N.

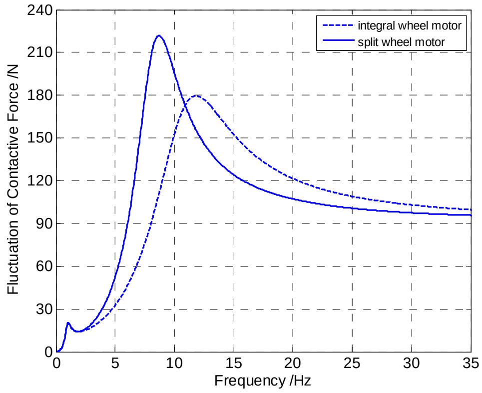


Figure 9. Fluctuation of contactive force

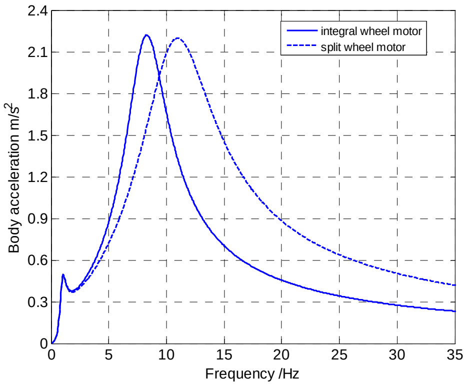


Figure 10. Comparison of body acceleration

At low stiffness of suspension and tire, the body acceleration is decreased dramatically too. As is shown in Fig.9, the max acceleration of body is subequal between the EV with integral motor and split motor.

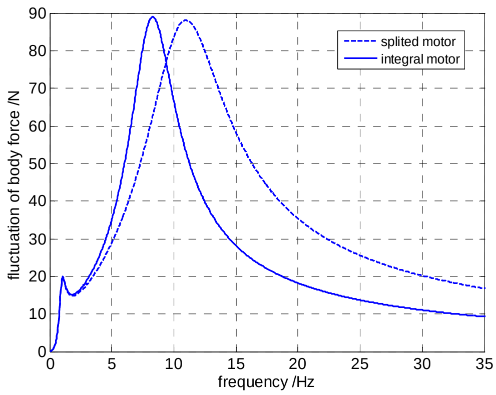


Figure 11. Fluctuation of body force

The fluctuation of body vertical force is shown in Fig.10. The max fluctuation amplitude of EV with integral motor and split motor has less difference.

Based on forgoing analysis, the increasing of unsprung mass for electric vehicle with integrated-motorized wheel has less influence on road holding performance and vehicle comfort when the stiffness of suspension and tire is low.

IV Vibration Analysis of Suspended-Motor Motorized Wheel

The same as the engine, suspension of motor used in connection with wheel can downsize the vibration degree of unsprung mass.

A. Vibration model of EV with suspended-motor motorized wheel

Fig.11 shows the model of suspended motor connected with the wheel. Because the motor is suspended up, the system becomes the 3-degree model in which the motor has its independent vibration degree. In the model, k_3, c_3 are the elastic constant and damping of the suspension between the in-wheel motor and wheels. m_3 is the mass of in-wheel motor. x_3 is the vertical displacement of in-wheel motor. F_d is the force acting on the motor. Other parameters are defined the same as in Fig.5. Here the m_1 does not include the motor mass.

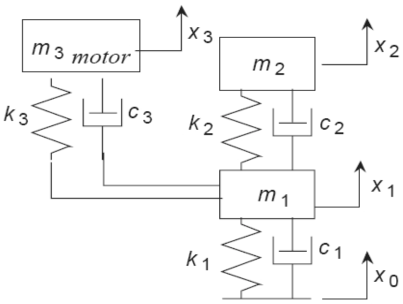


Figure 12. 1/4 vibration model of vehicle with suspended-motor motorized wheel

$$m_1 \ddot{x}_1 + F_n + F_t + F_d = 0$$

$$m_2 \ddot{x}_2 + c_2\left(\dot{x}_2 - \dot{x}_1\right) + k_2\left(x_2 - x_1\right) = 0$$

$$m_3 \ddot{x}_3 + c_3\left(\dot{x}_3 - \dot{x}_1\right) + k_3\left(x_3 - x_1\right) = 0$$

$$F_t = k_1\left(x_1 - x_0\right) + c_1\left(\dot{x}_1 - \dot{x}_0\right)$$

$$F_n = k_2\left(x_1 - x_2\right) + c_2\left(\dot{x}_1 - \dot{x}_2\right)$$

$$F_d = k_3\left(x_1 - x_3\right) + c_3\left(\dot{x}_1 - \dot{x}_3\right)$$

B. Analysis of road holding performance and comfort

Simulation model were made using simulink software. After providing the model the same excitation signals indicated before, simulation analysis was fulfilled for the frequency of the road holding force fluctuation and the vehicle body acceleration. In simulation, m_3 =20kg, k_3=32000 (N/m), c_3=1000 (N/(m/s)), other parameters are shown in Table.I and Tab.III. Results are shown in Fig.13 and Fig.14.

From Fig.13, the road holding performance was improved a lot by the suspending of in-wheel motor. The amplitude near the resonant frequency had also been downsized a lot compared with before. The peak value of road holding force fluctuation was smaller than that of detached type.

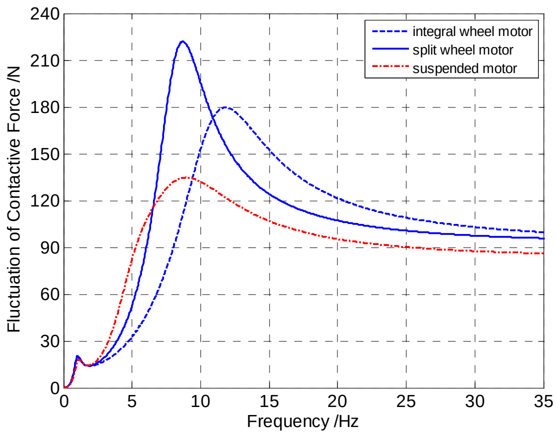


Figure 13. road holding performance by Suspended-motor

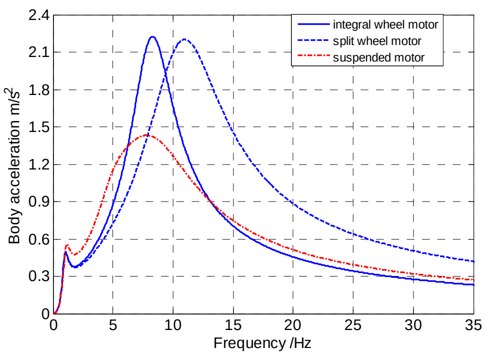


Figure 14. Vehicle Body Acceleration with Suspended-motor

From Fig.14, it can be seen that the vehicle body acceleration using suspended-motor motorized wheels is much smaller than that using integrated-motorized wheel and that using detached-motorized wheels.

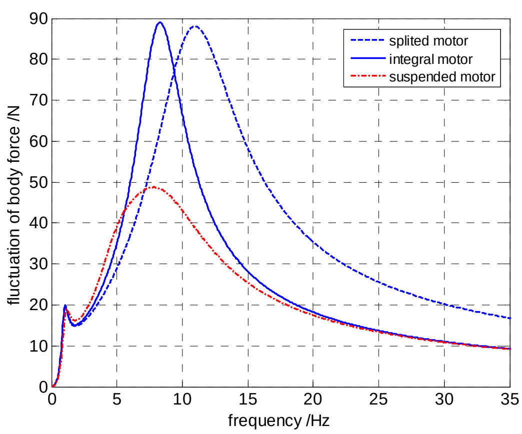


Figure 15. Fluctuation of body force with suspended motor

From Fig.15, the body vertical force fluctuation amplitude was decreased a lot by the suspending of in-wheel motor. The amplitude near the resonant frequency had also been downsized a lot compared with before.

Based on the analysis above, the adverse effects on vehicle's road holding performance and comfortableness caused by the increasing of unsprung mass for EV with integrated-motorized wheels can be improved remarkably by suspending of in－wheel motor The stiffness and damping of suspended part should match the ones of the wheel and the suspension.

V. SIMULATION WITH WHOLE VEHICLE MODEL

A. *Vehicle body model*

The whole vehicle model is shown in Fig.16.

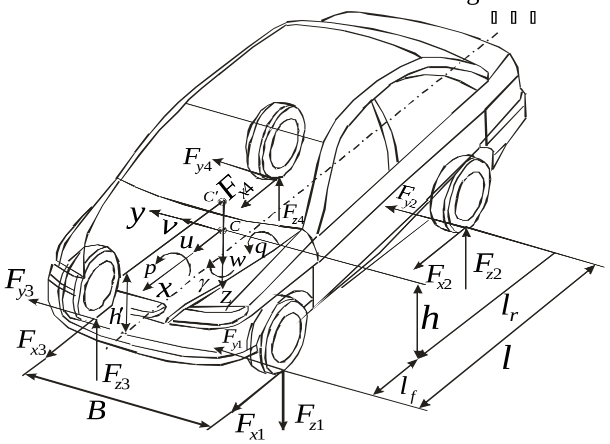


Figure 16. vehicle body model

To make comprehensive analysis for performance of electric vehicle with motorized wheels, the six freedom is included in body model. u , v , w is longitudinal speed, side speed and vertical velocity of sprung mass respectively. r , p , q is yaw velocity, roll velocity and pitch velocity of sprung mass. And ϕ , θ is roll angle and pitch angle of sprung mass. ψ is the yaw angle of vehicle.

F_{xi}, F_{yi}, F_{zi} ($i = 1, 2, ...4$) is the force acting on the vehicle by tire along coordinate axis. C is the center of vehicle mass. h is the height of vehicle mass center, C' is the height of sprung mass, h' is the distance from center of sprung mass to roll axis. B is the track width， l is the wheelbase. l_f, l_r is the distance from mass center to front axle and to rear axle respectively.

B. *Suspension model*

The action point and direction of the force between the body and wheels is decided by suspension model. To describe the influence on vehicle performance for increasing unsprung mass by using motorized wheels, the suspension model is made as shown in Fig.17[8]. The C' is the center of sprung mass, K_{ui}, C_{ui} ($i = 1, 2, ...4$) are the vertical stiffness and damping coefficient of the tires. K_{si}, C_{si} ($i = 1, 2, ...4$) are the stiffness and coefficient of suspensions, Z_{ui} is the height of unsprung mass, Z_{ri} is the roughness of the road. Z_s is the height of sprung mass.

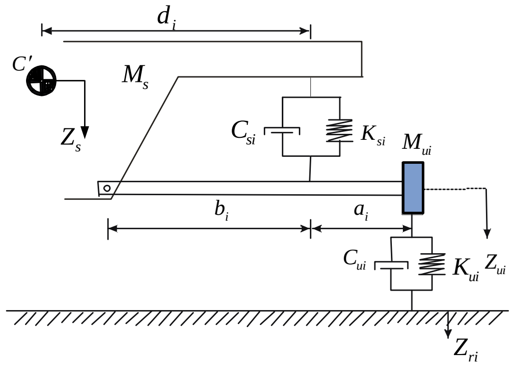


Figure 17. suspension model

The detailed description inclusive of the dynamics equation of the vehicle model is presented in literature 11.

C. *Step response simulation*

A condition that vehicle is driving on a road with a jump is simulated. The sudden change for the height of jump is shown in Fig.18. The road height changes to 0.1m steeply at 6s during vehicle driving and decreases to 0 m from 6.5s quickly.

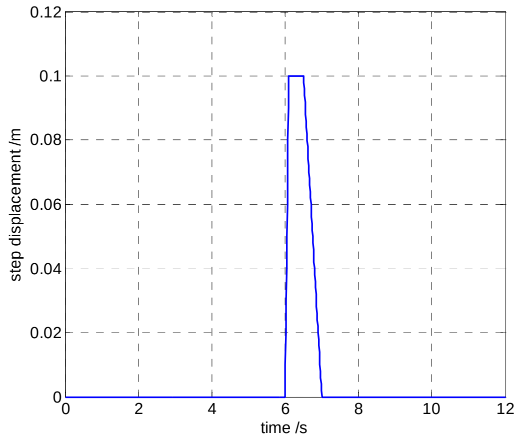


Figure 18. Jump during driving

The comparative result of the vertical acceleration of vehicle mass center between the vehicle with split in-wheel motor and integral in-wheel motor is shown in Fig.19. It is can bee seen from result that the acceleration of vehicle with split motor is bigger than with integral motor when the vehicle driving on the jump. The acceleration of wheel center of vehicle with split motor is bigger than with integral motor too, as is shown in Fig.20. It can be concluded that the vibration is improved when driving on the jump for increasing unsprung mass by integral in-wheel motor.

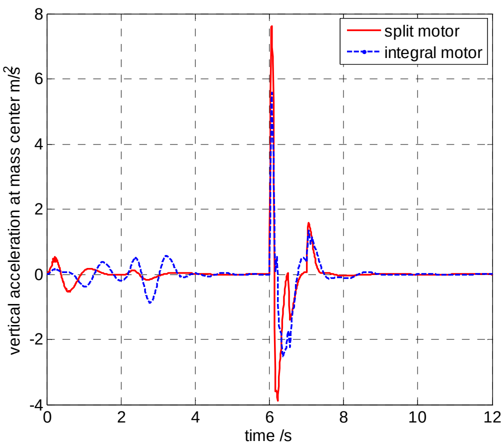


Figure 19. Vertical acceleration of vehicle mass center

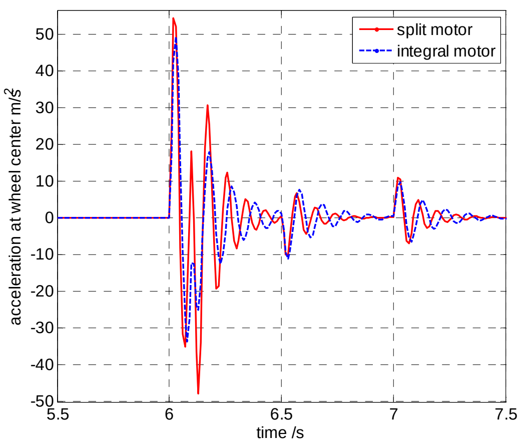


Figure 20. Vertical acceleration of wheel center

D. Driving on the rough road with sine of 15hz

The road roughness during simulation is shown in Fig.21.

The comparative acceleration of vehicle mass center with split motor and with integral motor is shown in Fig.22. The vertical acceleration of vehicle mass center is decreased by using integral motor comparing with split motor when driving on the rough road with with sine of 15Hz. Similarly, shown in Fig.23, the vertical acceleration of wheel center is decreased too by using integral motor. And so the vehicle comfort performance and road holding performance is improved by increasing unsprung mass for using integral motor at rough road of sine with 15Hz.

As shown in Fig.6 and Fig.7, the frequency of 15Hz is bigger than the resonant frequency of vehicle and wheel vibration system. And the vertical acceleration of vehicle mass center with integral motor is less than with split motor at this frequency. The same result is achieved by simulation with quarter vehicle model and whole vehicle model.

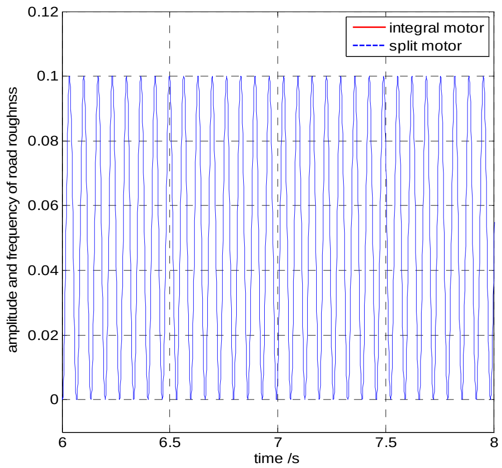


Figure 21. Road roughness of sine with 15Hz

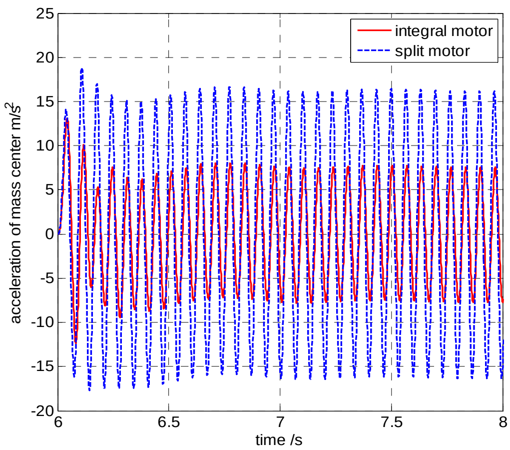


Figure 22. Vertical acceleration of vehicle mass center

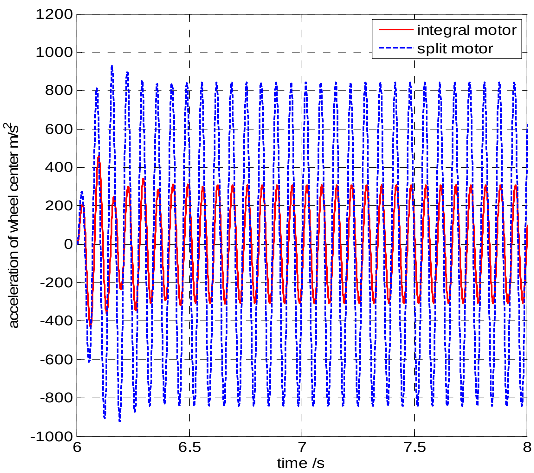


Figure 23. Vertical acceleration of wheel center

E. Driving on the rough road with sine of 10Hz

The road roughness during simulation is shown in Fig.24.

The acceleration of vehicle mass center with split motor and with integral motor is shown in Fig.25. the vertical acceleration of vehicle mass center is increased obviously by using integral motor comparing with split motor when driving on the rough road with sine of 10Hz. Similarly, the vertical acceleration of wheel center with integral motor is bigger than with split motor too, as shown in Fig26. And so the vehicle comfort performance and road holding performance is worsen by increasing unsprung mass for using integral motor at rough road of sine with 10Hz.

As shown in Fig.6 and Fig.7, the frequency of 10Hz is close to the resonant frequency of vehicle and wheel vibration system. And the vertical acceleration of vehicle mass center with integral motor is bigger than with split motor at this frequency. The same result is achieved by simulation with quarter vehicle model and whole vehicle model.

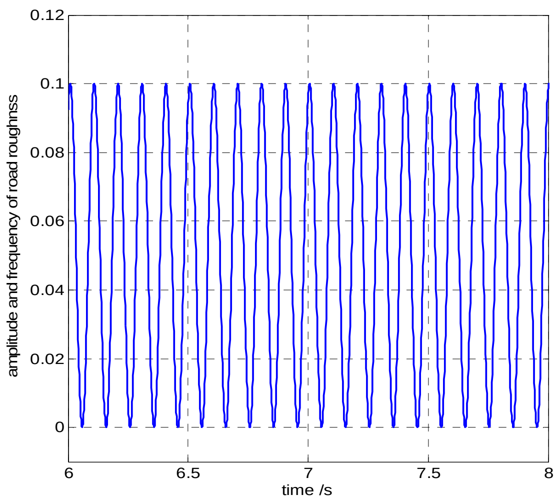


Figure 24. Road roughness of sine with 10Hz

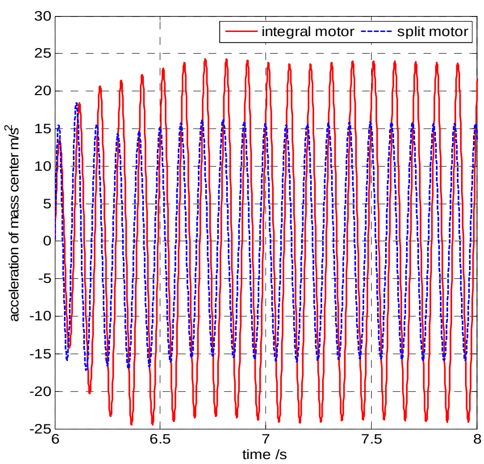


Figure 25. Vertical accelertation of mass center

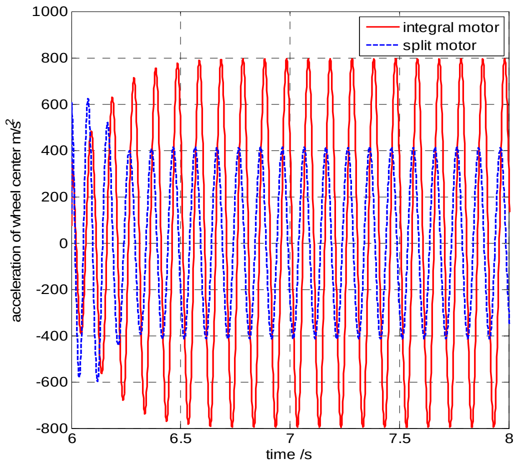


Figure 26. Vertical acceleration of wheel center

The increasing of unsprung mass by using integral motor deteriorates the vehicle comfort and vibration performance at low excitation frequency of road. But it is improved by using integral motor at higher excitation frequency of road, while unsprung mass is increased by using integral motor. The fluctuation amplitude of vibration at high frequency is much more big than at low frequency. In this view, the in-wheel motor that is integrated into wheels is acceptable structural concept for electric vehicle with motorized wheels with lower cost than suspended in-wheel motor.

V Conclusion

In this paper, structures of motorized wheels used in EV driving system were analyzed. Both detached-motorized wheel and integrated-motorized wheel have their merits and demerits. Detached-motorized wheel is easier to be mounted; Motor could works under good conditions; It is also easy to modified a conventional vehicle into a vehicle with motorized wheels. Integrated-motorized wheel requires much less place in layout. But the motor would works under terrible conditions, so high motor performance is required. To eliminate the adverse effect of increasing of unsprung mass, motor in integrated-motorized wheel should be suspended up. The vehicle with suspended in-wheel motor is much better than split motor and integral motor in comfort and road holding performance. Also, the stiffness and damping matching of suspended part should be taken with the wheel and suspension system. For high cost of suspended in-wheel motor, The effect of increasing of unsprung mass by using integral motor is analyzed. The more unsprung mass of integral motor deteriorates the vehicle comfort and vibration performance at low excitation frequency of road. But it is improved by using integral motor at higher excitation frequency of road, while unsprung mass is increased by using integral motor. The fluctuation amplitude of vibration at high frequency is much more big than at low frequency. In this view, the conclusion that in-wheel motor integrated into wheels is acceptable structural concept for electric vehicle with motorized wheels with lower cost than suspended in-wheel motor is achieved.

Motorized wheel drive system used in EV can help downsize the overall mass, reduce the developing costs and improve the vehicle's performance. It is a kind of technology that of great potential of application.

ACKNOWLEDGMENT

The authors gratefully acknowledge the funding for this effort provided by the National Natural Science Funding of China.

REFERENCES

[1] Peter C. Cho, William Wylam, David Crecelius. Advanced Hybrid Electric Vehicle Propulsion Systems With Individual Wheel Brushless Traction Motors. SAE 2000-01-3110
[2] Se-Kyo Chung, Hyun-Soo Kim, Chang-Gyun Kim, and Myung-Joong Youn. A New Instantaneous Torque Control of PM Synchronous Motor for High-Performance Direct-Drive Applications. IEEE TRANSACTIONS ON POWER ELECTRONICS, VOL. 13, NO. 3, MAY 1998
[3] Rao S. Zhou and Fukuo Hashimoto. Highly Compact Electric Drive for Automotive Applications. SAE2004-01-3037
[4] JIN Li-qiang, WANG Qing-nian, SONG Chuan-xue. Simulation for Optimal PD Control for Dynamics Control of EV with Motorized Wheels. Journal of System Simulation，Vol.19 No.10， 2007
[5] Y. Hori, Y. Toyoda, and Y. Tsuruoka. Traction control of electric vehicle: Basic experimental results using the test EV "UOT Electric March". IEEE Transaction. Industry. Application., Vol. 34, No. 5, pp. 1131–1138, 1998
[6] F.Carricchi, F.crescimbini, E.santini. Axial Flux Electromagnetic Differential induction motor. 'Electric Machines and drives' Conference Publication No.412,11-13 September 1995, IEE, P1—5
[7] Yee-Pien Yang _, Chun-Pin Lo.Current distribution control of dual directly driven wheel motors for electric vehicles. Control Engineering Practice. 16 (2008) 1285﹣1292
[8] Masayuki Terashima, Tadashi Ashikaga. Novel Motors and controllers for high Performance Electric Vehicle with Four In-Wheel Motors. IEEE Transactions on Industrial Industrial electronics, VOL. 44, NO. 1, FEBRUARY 1997. p28-38
[9] T. Ram Mohan Rao and G. Venkata Rao. PARAMETRIC SENSITIVITY ANALYSIS OF A HEAVY DUTY PASSENGER VEHICLE SUSPENSION SYSTEM. ARPN Journal of Engineering and Applied Sciences. NO. 8, VOL. 4, OCTOBER 2009
[10] Hyeongcheol Lee and Masayoshi Tomizuka. Adaptive Vehicle Traction Force Control for Intelligent Vehicle Highway Systems (IVHSS). IEEE Transactions on Industrial Industrial electronics, NO.1, VOL.50, FEB 2003 p37-47
[11] Jin Li-qiang , Wang Qing-nian , Song Chuan-xue.Dynamic simulation model and experimental validation for vehicle with motorized wheels. Journal of Jilin University (Engineering and Technology Edition). No.4, Vol.37, 2007, p745-750

JIN Li-qiang received the B.S. from College of Mechanical Engineering, Hebei University of Technology, Tianjin, China in 1999. And Received M.S. and Ph.D. degrees from the College of Automotive Engineering, Jilin University, Changchun, China, in 2002 and 2006, respectively.

He is currently a Assistant Professor with the College of Automotive Engineering, Jilin University. His research areas include modeling and control of vehicle systems, Advanced Technology and theory of Electric vehicle with motorized wheels.

SONG Chuan-xue received the B.S. M.S. and Ph.D. degrees from the College of Automotive Engineering, Jilin University, Changchun, China, in 1982 1985 and 1991, respectively.

He is currently a Professor with the College of Automotive Engineering, Jilin University. His research areas include Theory and Control of Vehicle Dynamics.

WANG Qing-nian received the B.S. M.S. and Ph.D. degrees from the College of Automotive Engineering, Jilin University, Changchun, China, in 1978 1983 and 1987, respectively.

He is currently a Professor with the College of Automotive Engineering, Jilin University. His research areas is Theory and Control of Hybrid Electric vehicle.