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Using Of In-Wheel Motors in Passive Suspension System

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Abstract
The goal of this paper is to present evaluation about the effect of in-wheel electric motors mass on the performance of passive suspension system. In-wheel electric motor mass which is also called unsprung mass is one of the main important parameters which effects on ride comfort and road holding behaviors in the vehicles, this effect will be obtained in this work. To achieve the goal of this work, modeling and simulation of car quarter model is completed to implement the Simulink model of the system using MATLAB software. The computer simulations show bad effect of increasing the mass of tires by add In-Wheel Electric Motors IWEM to the system on the vehicles drivers' comfort and road traction.

Keywords: suspension system, In-wheel motors, unsprung mass, quarter car model, Simulink model

Introduction
Primary suspension is a term used to designate those components of suspension connecting the axle and wheel which assemblies of a car to the frame of the car. This is in contrast to the suspension components connecting the body of the vehicle and the frame, or those the components located directly at the car's seat, generally called the secondary suspension system. There are two basic kinds of elements in conventional suspension system. These elements are dampers and springs. The role of the spring in a car's suspension systems is to support the car static weight while, the role of the damper is to dissipate vibrations in energy and control the input from the road which is transmitted to the car. The main function and form of the suspension is the same regardless of the car type or suspension. Primary suspensions can be divided into passive suspension, active adjustable suspension and semi-active suspension systems [1].
The passive suspension system is one in which the components characteristics (springs and dampers) are designed as fixed characteristics. These characteristics are determined by the suspension designer, according to the design intended application and goals. Design of passive suspension is a compromise between car handling and the ride comfort [1].
The heavily damped suspension will produce good car handling, but also will transfer much of the road input to the car body. When the car is moving at low velocity on rough road or at high velocity in a straight line, this will be caused as a harsh ride. The car operators may find a harsh ride objectionable, or the cargo may damage. The lightly damped suspension will produce more comfortable riding, but can reduce the stability of the car significantly in turns and lane change maneuver, or due to negotiating an exit ramp. The good design of the passive suspensions can to some extent stability and optimize ride, but cannot prevent this compromise.

In-Wheel motor structure
The in-wheel motors IWM (also called hub motors, wheel motors, wheel hub drive, or wheel hub motors) are an electric motors that are incorporated into the wheel hub and drives it directly. In this paper, only the effect of electric motor mass will take into considerations [2].
Figure 1 is the cross-section of the in-wheel motor system, which has a structure that aligns the hub, reducer section and the motor section in a series configuration and figures 2 and 3 illustrate the Michelin wheel with an in-wheel electric motor and Bridgestone's

Dynamic-Damping In-wheel electric Motor Drive System [2].

Fig. 1: In-wheel electric motor system.

Fig. 2: Michelin active tire with in-wheel electric motor.

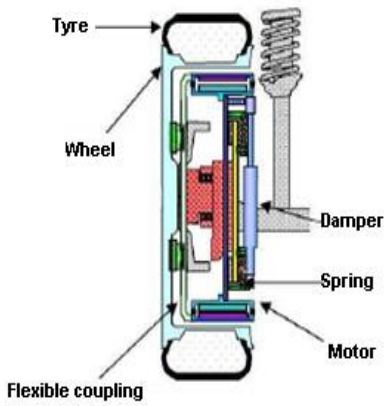

Fig.3: Bridgestone's Dynamic-Damping In-wheel electric motor Drive System.

Passive suspension system mathematical model

Designing and study the passive suspension system is an interesting and challenging of comfort problems. Also, Suspension system modeling can serve two purposes: developing the performance of the cars and understanding the system dynamics. Model is simplified the physical systems representation, allowing focus on important system dynamic. When the passive suspension system is designed, the quarter car model (one of the four tires) is used to simplify the system to a 1D multiple damper-spring system. A diagram of the passive suspension system is shown below.

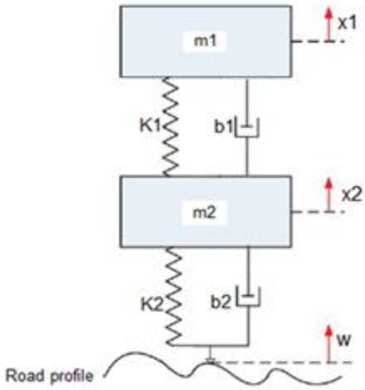

Fig. 4: Quarter car model passive suspension system.

Based on the second Newton law, it can easy to derive the mathematical equations of the motion for passive suspension system which given as following:

$$m_1\ddot{x}_1 = -K_1(x_1 - x_2) - b_1(\dot{x}_1 - \dot{x}_2) \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (1)$$

$$m_2\ddot{x}_2 = K_1(x_1 - x_2) + b_1(\dot{x}_1 - \dot{x}_2) - K_2(x_2 - w) - b_2(\dot{x}_2 - \dot{w}) \quad \ldots (2)$$

Where:
(w) is the road profile.
(x_1) is the displacement of the car body.
(x_2) is the displacement of the un-sprung mass.
(b_1) is the damping constant of the system =1020 N.m/s.
(b_2) is the damping constant of the wheel =0 N.m/s.
(K_1) is the spring stiffness constant =16100 N/m.
(K_2) is the wheel stiffness constant =158000 N/m.
(m_1) is the quarter car body mass or the sprung mass =242 Kg.
(m_2) is the unsprung mass =39 Kg.
(mi) is the unsprung mass with in-wheel electric motor =(39+34)Kg*
*The unsprung mass with in-wheel electric motor = (wheel mass+ In-wheel electric motor mass.
*The electric motor mass is assumed as 79Ibs (about 34Kg) which is selected from Protean Electric productions.

Passive suspension system Simulink model

Figure 5 obtains the Simulink model of the car passive suspension system for quarter car model which is built based on the mathematical equations 1 and 2.

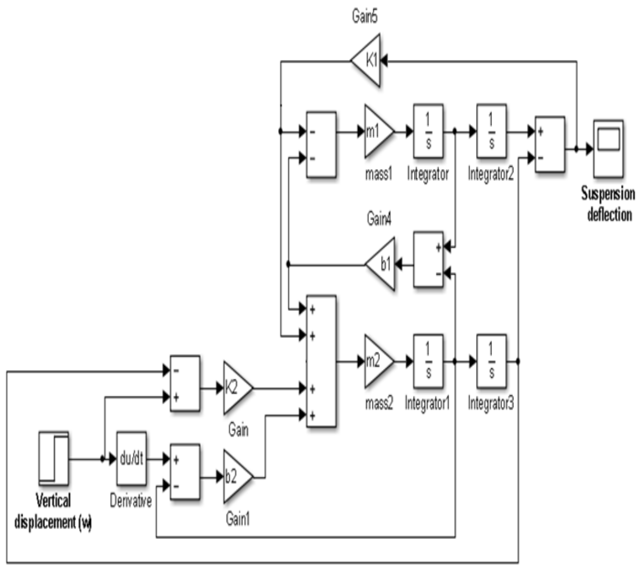

Fig. 5: Simulink model diagram of passive suspension system.

Simulation results

From the Simulink model diagram shown in figure 5, it can see all the results of the system characteristics and behavior where, Figures 6 to 10 show results and analysis of passive suspension system performance for a quarter car model for speed bump of - 0.1 m (represents a step input) and the effect of in-wheel electric motor mass IWM on the system behavior.

Figure 6 shows the effect of In-Wheel motor mass on the deflection of the suspension system. It is obvious that using of In-Wheel motor increases the suspension deflection and caused a bad effect of the system performance. The other figures show the effect of In-Wheel motor mass on the tire deflection, the effect of In-Wheel motor mass on the velocity of sprung mass, the effect of In-Wheel motor mass on the velocity of unsprung mass, and the effect of In-Wheel motor mass on the acceleration of sprung mass respectively,

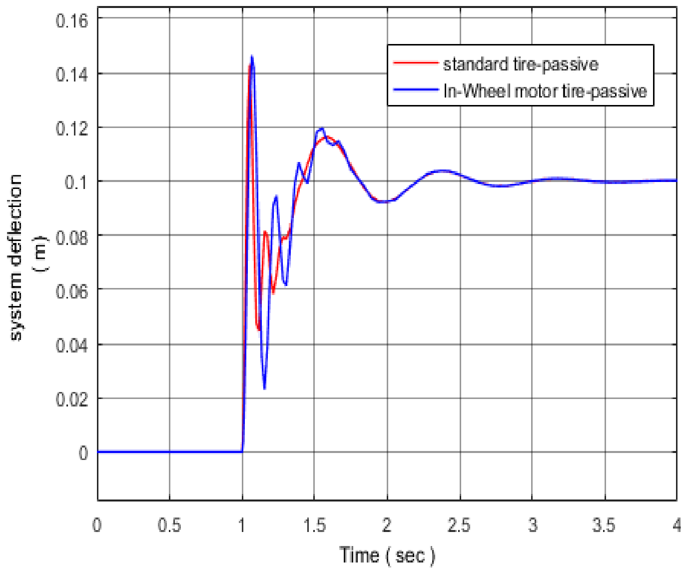

Fig. 6: Effect of In-Wheel motor mass on the suspension deflection.

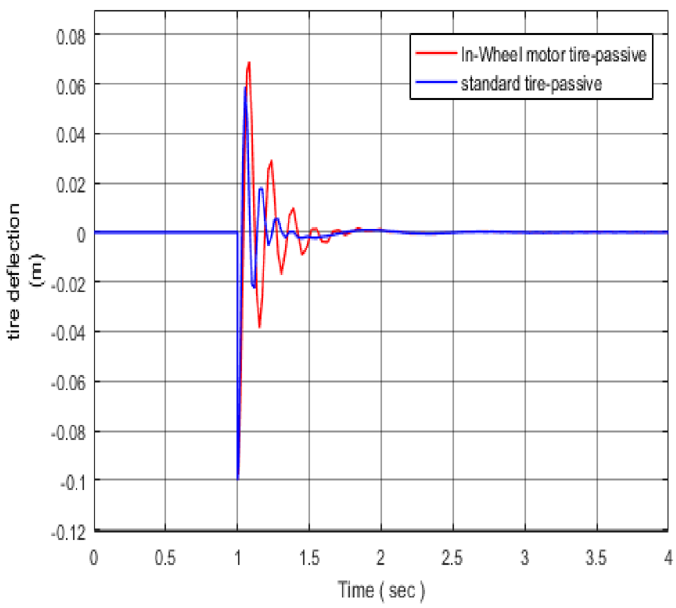

Fig. 7: Effect of In-Wheel motor mass on the tire deflection.

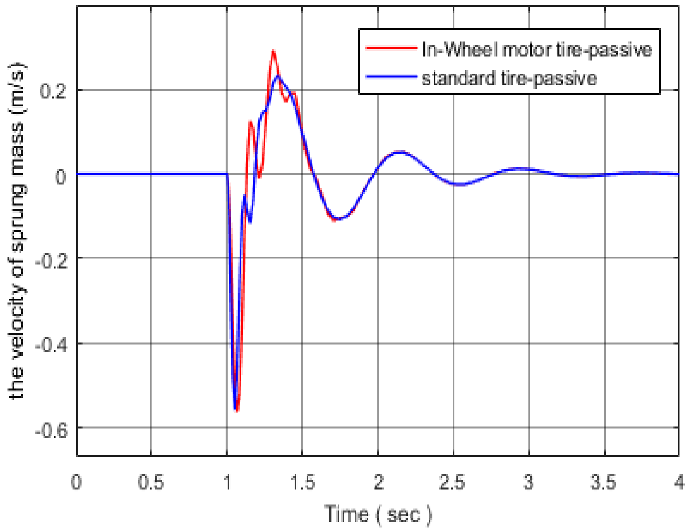

Fig. 8: Effect of In-Wheel motor mass on the velocity of sprung mass.

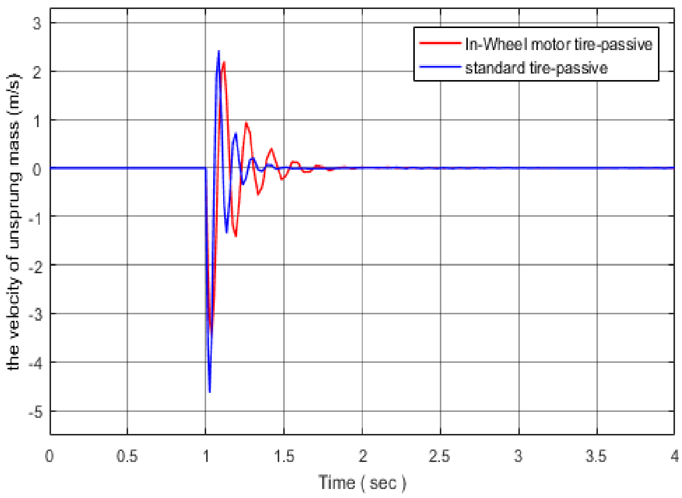

Fig. 9: Effect of In-Wheel motor mass on the velocity of unsprung mass.

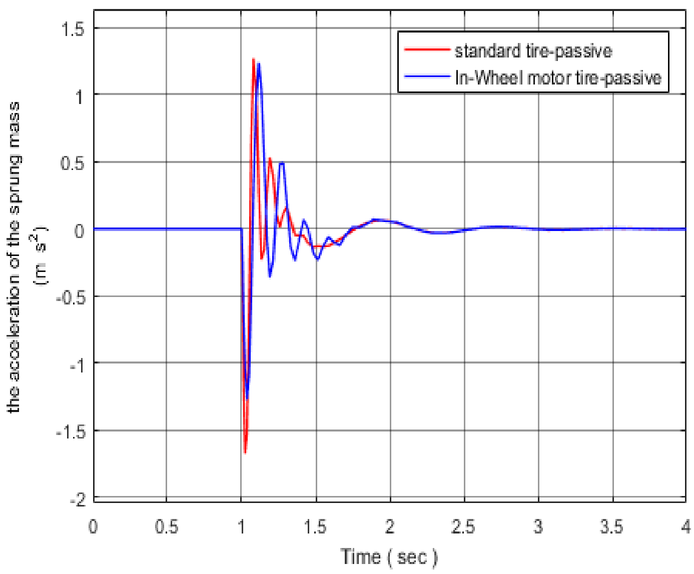

Fig. 10: Effect of In-Wheel motor mass on the acceleration of Sprung mass.

Conclusion

This paper shows a comparison between a passive suspension system with standard tire and in case of in-wheel electric motor. There was a significant effects of the in-wheel electric motor mass on the passive suspension system behavior and performance, some of these effects were clear in the sprung mass velocity and suspension system deflection which represents the driver ride comfort and the road traction respectively. Finally, using of in-wheel electric motor in the cars has various bad effects which caused a little reliability to use it.

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