https://doi.org/10.31871/WJRR.16.6.11
World Journal of Research and Review (WJRR)
ISSN: 2455-3956, Volume-16, Issue-6, June 2023 Pages 12-15

Optimal Design Parameters of In-Wheel Motor Suspension System using Genetic Algorithm

Tran Duc Hoang, Nguyen Thi Hong Ngoc, Le Van Quynh, Nguyen Dinh Tan, The Minh Huong

***Abstract*— The aim of this study is to propose an optimal design method for In Wheel Motor (IWM) suspension system of an electric vehicle (EV) so that the ride comfort can be improved. a 3-DOF quarter-vehicle dynamic model of an electric vehicle under two input excitation sources such as road surface roughness excitation and in-wheel motor excitation is established for the optimal design parameters of IWM suspension system using Genetic Algorithm (GA). The root-mean-square (RMS) acceleration of the vertical vehicle body according to the international standard ISO 2631-1 (1997) is selected as objective function. The study results indicate that the a_{wb} values of GA optimal parameters reduce significantly in comparison with those of the original parameters of IWM suspension system, which means that the performance optimization of IWM suspension system is better than the original IWM suspension system of electric vehicle in improving the ride comfort of electric vehicle.**

***Index Terms*—electric vehicle, In Wheel Motor (IWM), IWM suspension system, optimal design parameters, ride comfort.**

I. INTRODUCTION

Currently, electric vehicles (EVs) are replacing traditional vehicle using internal combustion engines reduce environmental pollution in countries around the world. The company's electric vehicle development trend focuses on the directions of battery technology, vehicle speed and vehicle safety and vehicle comfort. To enhance the ride comfort of EVs, the suspension systems is one of the important systems that many researchers focus on in recent years. Hoang Anh Tan, et al, (2021) proposed a quarter dynamics model of electric vehicle to investigate the effect of design parameters of In-Wheel Motor (IWM) suspension system on vehicle ride comfort [1]. L. V. Quynh, et al (2019) a quarter dynamics model of electric vehicle under the combination of IWM and road surface roughness excitations to analyze the impact on the vehicle ride comfort caused by IWM suspension system [2]. Yechen_Qin, et al, (2018) proposed a new approach for vibration mitigation based on a dynamic vibration absorbing structure (DVAS) for electric vehicles (EVs) that use in-wheel switched reluctance motors (SRMs) to alleviate the negative effects of vibration caused by the unbalanced electromagnetic force (UMEF) that arises from road excitations [3]. Yu, B., et al, (2019) proposed a 2 degree-of-freedom quarter car model of an electric mini off-road vehicle to to investigate the ride comfortability [4]. In order to enhance the electric vehicle ride comfort, the optimization, control, and optimal control methods are used to control EVs suspension systems. Quynh, L.V., et al (2023) proposed a modified Skyhook controller to control the damping coefficient of EV suspension system using a three-degree-of-freedom EV dynamic model under two excitation sources such as road surface excitation and in-wheel electric motor (IWM) excitation [5]. Liu M., (2017) proposed an in-wheel vibration absorber for in-wheel-motor electric vehicles (IWM EVs) and a linear quadratic regulator (LQR) algorithm was used to control suspension damper to improve vehicle ride comfort and meanwhile a fuzzy proportional-integral-derivative (PID) method is developed to control in-wheel damper as well [6]. D. Tan, et al (2016) proposed a 14-degree of freedom coupled vehicle dynamic model to control the active suspension system of an electric vehicle driven by two rear in-wheel motors using dual-loop PID control with PSO algorithm [7]. Yang, Z., et al (2018) proposed an improved genetic algorithm based on fitness evaluation to optimize the suspension system of EV using a virtual dynamics model of electric vehicle in ADAMS software [8]. Le V. Q., Nguyen K. T., (2018) proposed a multi-objective optimization method based on the improved genetic algorithm NSGA-II to optimize the design parameters of cab's isolation system when vehicle operates under the different conditions [9]. L. V. Quynh, et al, (2011, 2020) proposed an optimal design for cab's isolation system of vibratory roller using CAE software [10], [11]. L. Quynh, et al, (2020) proposed an optimal design method for drum's isolation systems of a double-drum vibrating roller so that the ride comfort can be improved using genetic algorithm (GA). N. V. Tuan, (2020) proposed a half-vehicle dynamic model under the road-vehicle interaction with 12 degrees of freedom (d.o.f) for searching the optimal design parameters of vehicle suspensions using genetic algorithm (GA)[13], [14].

In this study, a 3-DOF quarter-vehicle dynamic model of an electric vehicle under two input excitation sources such as road surface roughness excitation and in-wheel motor excitation is established based on reference [1] for the optimal design parameters of IWM suspension system using Genetic Algorithm (GA). The weighted r.m.s acceleration responses of the vertical driver's seat and pitch angle of the cab according to the ISO 2631:1997(E) standard [15] are chosen as the objective functions. Matlab/Simulink software was used to simulate the vehicle dynamic model and calculate the values of the objective function.

Tran Duc Hoang, Faculty of Vehicle and Energy Engineering, Thai Nguyen University of Technology, Thai Nguyen, Vietnam

of Vehicle and Energy Engineering, Thai Nguyen University of Technology, Thai Nguyen, Vietnam

Le Van Quynh, Faculty of Vehicle and Energy Engineering, Thai Nguyen University of Technology, Thai Nguyen, Vietnam

Nguyen Dinh Tan, Faculty of Mechanical Engineering, East Asia University of Technology, Bac Ninh, Vietnam

The Minh Huong, Viet Nam – Korea College of Quang Ninh, Quang Ninh, Vietnam

II. MATHEMATICAL MODEL OF IWM EV

A. Quarter-Vehicle Dynamic Model [1]

A quarter-vehicle dynamic model of in-wheel-motor electric vehicle (IWM EV) with three degrees of freedom and under two input excitation sources such as road surface roughness excitation is established to evaluate the effect of design parameter of in-wheel motor suspension system (IMSs) on electric vehicle ride comfort, as shown in Fig.1.

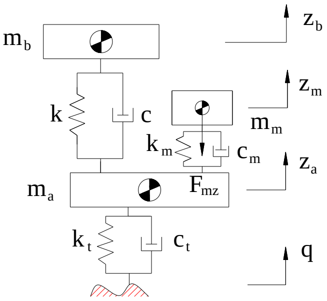

Figure.1: Quarter-vehicle dynamic model of IWM EV

Explanation of Fig.1, m_b is the vehicle body mass, m_m is in-wheel motor mass, m_a is vehicle axle mass, z_b, z_m and z_a are the vertical displacements of vehicle body, in-wheel motor, and vehicle axle masses, k,c, k_m, c_m, and k_t, c_t are the stiffness and damping coefficients of the vehicle and in-wheel motor suspension systems and tire, q is input excitation function of road surface and F_{mz} is the excitation function of in-wheel motor in the vertical direction.

B. Equation of motion [1]

The equations of vehicle motion can be formulated in different ways such as Lagrange's equation, Newton-Euler equation, Jourdain's principle. In this study, Newton-Euler equation is chosen to describe the equations of vertical motion of electric vehicle. From quarter-vehicle dynamic model of IWM EV as shown in Fig. 1, the dynamic equations of an electric vehicle are written as follows:

$$\begin{cases} m_b\ddot{z}_b = -\left[k\left(z_b - z_a\right) + c\left(\dot{z}_b - \dot{z}_a\right)\right] \\ m_m\ddot{z}_m = F_{mz} - \left[k_m\left(z_m - z_a\right) + c_m\left(\dot{z}_m - \dot{z}_a\right)\right] \\ m_a\ddot{z}_a = \left[k_m\left(z_m - z_a\right) + c_m\left(\dot{z}_m - \dot{z}_a\right)\right] + \\ +\left[k\left(z_b - z_a\right) + c\left(\dot{z}_b - \dot{z}_a\right)\right] - \left[k_t\left(z_a - q\right) + c_m\left(\dot{z}_a - \dot{q}\right)\right] \end{cases} \quad (1)$$

C. Input excitation

Road surface excitation function: Surface roughness plays an important role in evaluating the dynamic interaction between vehicles and road. It is simulated in space domain and acts as an input to the vehicle-road model. The road surface roughness irregularities can be represented with a normal stationary argotic random process described by its Power Spectral Density (PSD). According to the International Standards Organization (ISO) 8608 [11], PSD of road roughness can be defined as Eq. (2):

$$G_q(n) = G_q(n_0)\left(\frac{n}{n_0}\right)^{-w} \quad (2)$$

where, n is spatial frequency in m^{-1}, n_0 is reference spatial frequency with a value of $0.1m^{-1}$, $G_q(n_0)$ is PSD value for reference spatial frequency in m^3, w is termed waviness, and reflects approximate frequency structure of the road profile, commonly taken as w=2. The classification of road roughness is based on the index of International Organization for Standardization ISO 8608. The ISO has proposed road roughness classification from class A - very good to class H - very poor, according to different values of $G_q(n_0)$. The road profile is generated as the sum of a series of harmonics:

$$q(t) = \sum_{k=1}^{N}\sqrt{2G_q\left(n_k\right)\Delta n}\cos\left(2\pi n_k t + \phi_k\right) \quad (3)$$

ϕ_k is the random phase uniformly distributed from 0 to2π; $G_q(n_k)$ is the power spectral density (PSD) function (m^3/cycle) for the road surface elevation; n_k is the wave number (cycle/m).

In-wheel motor excitation function [1]: The excitation function of in-wheel motor in the vertical direction is determined by

$$F_{mz} = m_s e\omega_R^2\cos\omega_R t \quad (4)$$

where, m_s is the total mass of the tire, the rim and the motor rotor; e is the eccentricity of the rotor; ω_R is the angular velocity of the rotor.

III. OPTIMAL DESIGN PARAMETERS VIA GENETIC ALGORITHM [12]

The genetic algorithm is a technique adapted from the evolutionary adaptation of biological populations by Darwinism. GA is a method of random optimization by mimicking the evolution of humans or organisms. Its idea is to simulate natural phenomena inheriting and fighting for survival. A simple genetic algorithm consists of the following steps: Step 1: Initialize a population of chromosome sequences; Step 2: Determine the target value for each corresponding chromosome; Step 3: Create new chromosomes based on genetic operators; Step 4: Eliminate low adaptive chromosomes; Step 5: Define the target function for new chromosomes and population inclusion. Step 6: Check whether the stop condition is satisfied. If the condition is right, get the best chromosome, and the algorithm stops; otherwise, go back to step 3.

Objective function: To improve the vehicle's ride comfort, the optimal design parameters of IWM suspension system are found out so that the value of the weighted root mean square (rms) of acceleration response of vehicle body vertical vibration should be minimized:

$$F(X)=a_{wb}(X)_{\rightarrow\min} \quad (5)$$

where, $X=[k_m,c_m]$ is the design parameter vector of IWM suspension system; a_{wb} is the value of the weighted root mean square (rms) of acceleration response of vehicle body vertical vibration through Eq.(6), based on the ISO 2631:1997(E) standard

$$a_w = \left[\frac{1}{T}\int_0^T a^2(t)dt\right]^{\frac{1}{2}} \quad (6)$$

where, a(t) is the measured or simulated acceleration (translational and rotational) as a function of time, m/s^2; T is the duration of the measurement or the simulation time.

Boundary conditions: The objective function Eq. (8) must satisfy the following boundary conditions:

$$\begin{cases} 36000 \le k_m \le 98000 \\ 3000 \le c_m \le 6000 \\ \left|z_m - z_a\right| \le 0.086 \end{cases} \quad (7)$$

IV. SIMULATION AND DISCUSSION

In order to find out the values of the optimal parameters of IWM suspension system of an electric vehicle, Eq. (1) is solved through Matlab/Simulink environment with the initial vehicle design parameters as shown in Table 1. A program of genetic algorithm is written in Matlab to declare input parameters such as objective function Eq. (5), boundary conditions Eq. (7), and GA parameters such as population size as 50 and generation as 200, which called by Simulink module function using the sim function. When vehicle moves on ISO class B road surface at vehicle speed v=80 km/h and IWM vertical exciting force $F_{mz}=2207\cos(100\pi t)$/N, the optimal values of IWM suspension system of electric vehicle are obtained by GA method in comparison with the original parameters, as shown in Table 2.

Table 1. Parameters of an IWM electric vehicle

Parameters	Values	Parameters	Values
m_b/kg	388	k_t/(N/m)	220000
m_a/kg	32.5	c_t/(Ns/m)	50
m_m/kg	60	k_m/(N/m)	72591
k/(N/m)	22000	c_m/(Ns/m)	3019
c/(Ns/m)	1218		

Table 2. GA optimization parameters of IWM suspension system

Parameters	k_m/(N/m)	c_m/(Ns/m)
Original values	72591	1508
Optimal values by GA	49600	3200

The performances of the GA are compared with the original parameters of IWM suspension system of an electric vehicle with Case 1 (Case 1: When vehicle moves on ISO class B road surface at vehicle speed v=80 km/h and IWM vertical exciting force $F_{mz0}=2207\cos(100\pi t)$/N), as shown in Fig. 2.

From the results of Fig. 2, we can determine the value of the weighted rms acceleration of the vertical vehicle body a_{wb} according to Eq. (6), a_{wb} value is 0.3716 m/s^2 with the original parameters of IWM suspension system and 0.3158 m/s^2 with GA optimal parameters of IWM suspension system. The results show that the a_{wb} value with GA optimal parameters reduce by 17.67 % in comparison with the original parameters of IWM suspension system, which means that vehicle's ride comfort is improved significantly when the vehicle operates in this condition.

Similarity, the performances of the GA are compared with the original parameters of IWM suspension system of an electric vehicle with Case 2 (Case 2: When vehicle moves on ISO class C road surface at vehicle speed v=60 km/h and IWM vertical exciting force $F_{mz}=2207\cos(100\pi t)$/N) and with Case 3 (Case 3: When vehicle moves on ISO class D road surface at vehicle speed v=40 km/h and IWM vertical exciting force $F_{mz}=2207\cos(100\pi t)$/N)), as shown in Fig. 3 and Fig.4.

Similarity, from the results of Fig. 3, we can determine the value of the weighted rms acceleration of the vertical vehicle body (a_{wb}), a_{wb} value is 0.5831m/s^2 with the original parameters of IWM suspension system and 0.4840 m/s^2 with GA optimal parameters of IWM suspension system. The results show that the a_{wb} value with GA optimal parameters reduce by 20.47 % in comparison with the original parameters of IWM suspension system, which means that vehicle's ride comfort is improved significantly.

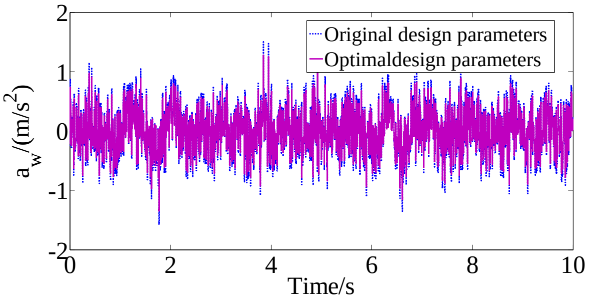

Figure 2: Comparison of acceleration responses of vehicle body before and after optimization with Case 1

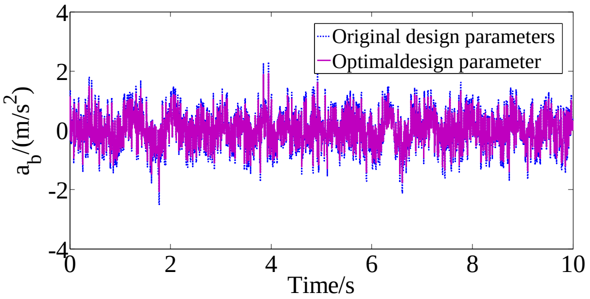

Figure 3: Comparison of acceleration responses of vehicle body before and after optimization with Case 2

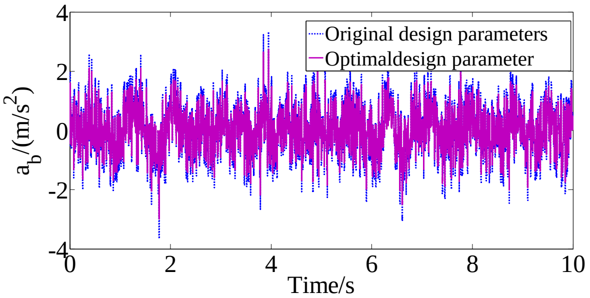

Figure 4: Comparison of acceleration responses of vehicle body before and after optimization with Case 3

Similarity, from the results of Fig. 4, we can determine the values of the weighted rms acceleration of the vertical vehicle body a_{wb}, is 0.8385/s^2 with the original parameters of IWM suspension system and 0.68757 m/s^2 with GA optimal parameters of IWM suspension system. The results show that the a_{wb} value with GA optimal parameters reduce by 21.95 % in comparison with the original parameters of IWM suspension system, which means that vehicle's ride comfort is improved significantly.

V. CONCLUSION

In this study, in order to enhance the electric vehicle ride comfort, a 3-DOF quarter-vehicle dynamic model of an electric vehicle under two input excitation sources such as road surface roughness excitation and in-wheel motor excitation is established based on reference [1] for the optimal design parameters of IWM suspension system using Genetic Algorithm (GA). The major conclusions can be drawn from the analysis results as follows:

i) a_{wb} value with Case 1 is 0.3716 m/s^2 with the original parameters of IWM suspension system and 0.3158 m/s^2 with GA optimal parameters of IWM suspension system. The results show that the a_{wb} value with GA optimal parameters reduce by 17.67 % in comparison with the original parameters of IWM suspension system, which means that vehicle's ride comfort is improved significantly.

ii) a_{wb} value with Case 2 is 0.5831m/s^2 with the original parameters of IWM suspension system and 0.4840 m/s^2 with GA optimal parameters of IWM suspension system. The results show that the a_{wb} value with GA optimal parameters reduce by 20.47 % in comparison with the original parameters of IWM suspension system.

iii) a_{wb} value with Case 3 is 0.5831m/s^2 with the original parameters of IWM suspension system and 0.4840 m/s^2 with GA optimal parameters of IWM suspension system. The results show that the a_{wb} value with GA optimal parameters reduce by 20.47 % in comparison with the original parameters of IWM suspension system.

ACKNOWLEDGMENT

This research was supported financially by Thai Nguyen University of Technology, TNUT, Viet Nam.

REFERENCES

[1] Hoang Anh Tan, Nguyen Thanh Cong, Le Hong Thai, "Effects of Design Parameter of In-Wheel Motor Suspension System on Electric Vehicle Ride Comfort," *World Journal of Research and Review (WJRR),* Volume-12, Issue-6, p. 29-32, https://doi.org/10.31871/WJRR.12.6.10.

[2] L. V. Quynh, B. V. Cuong, N. V. Liem, L. X. Long, and P. T. Thanh Dung, "Effect of in-wheel motor suspension system on electric vehicle ride comfort," *Vibroengineering PROCEDIA*, Vol. 29, pp. 148–152, Nov. 2019, https://doi.org/10.21595/vp.2019.21175

[3] Qin Y., He C., Shao X., Du H., Xiang C., Dong M. "Vibration mitigation for in-wheel switched reluctance motor driven electric vehicle with dynamic vibration absorbing structures, " *Journal of Sound and Vibration,* Vol. 419, 2018, p. 249-267, https://doi.org/10.1016/j.jsv.2018.01.010.

[4] Yu, B., Wang, Z., Wang, G., Zhao, J., Zhou, L., & Zhao, J. (2019). "Investigation of the suspension design and ride comfort of an electric mini off-road vehicle," *Advances in Mechanical Engineering*, 11(1), Vol. 11(1) pp. 1-10, https://doi.org/10.1177/1687814018823351.

[5] Quynh, L.V., Cuong, B.V., Tan, H.A., Huan, C.C. "Modified Skyhook Control for Semi-active Electric Vehicle Suspension," *Lecture Notes in Networks and Systems,* vol 602. Springer, Cham, https://doi.org/10.1007/978-3-031-22200-9_88

[6] Liu M., Gu F., Zhang Y., "Ride comfort optimization of in wheel-motor electric vehicles with in-wheel vibration absorbers," *Energies*, Vol. 10, 2017, p. 1647, https://doi.org/10.3390/en10101647

[7] D. Tan, C. Lu, and X. Zhang, "Dual-loop PID control with PSO algorithm for the active suspension of the electric vehicle driven by in-wheel motor," *Journal of Vibroengineering*, Vol. 18, No. 6, pp. 3915–3929, Sep. 2016, https://doi.org/10.21595/jve.2016.16689

[8] Yang, Z., Yong, C., Li, Z., & Kangsheng, Y., "Simulation analysis and optimization of ride quality of in-wheel motor electric vehicle," *Advances in Mechanical Engineering*, Vol.10(5), 168781401877654. doi:10.1177/1687814018776543.

[9] Le V. Q., Nguyen K. T., "Optimal design parameters of cab's isolation system for vibratory roller using a multi-objective genetic algorithm," *Applied Mechanics and Materials*, Vol. 875, 2018, p. 105-112. https://doi.org/10.4028/www.scientific.net/AMM.875.105

[10] L. V. Quynh, Z. Jianrun, N. V. Liem, B. V. Cuong, L. X. Long, and D. T. Phuong, "Experimental modal analysis and optimal design of cab's isolation system for a single drum vibratory roller," *Vibroengineering PROCEDIA,* Vol. 31, pp. 52–56, May 2020, https://doi.org/10.21595/vp.2020.21325.

[11] Quynh, Le Van, Jian Run Zhang, Guo Wang Jiao, Xiao Bo Liu, and Yuan Wang. "Vibration Analysis and Optimal Design for Cab's Isolation System of Vibratory Roller." Advanced Materials Research 199–200 (February 2011): 936–40. https://doi.org/10.4028/www.scientific.net/amr.199-200.936.

[12] L. Quynh, V. Thao, T. Phong, "Optimal design parameters of drum's isolation system for a double-drum vibratory roller", *Vibroengineering PROCEDIA,* Vol. 31, p. 74, 2020. https://doi.org/10.21595/vp.2020.21445

[13] N. V. Tuan, L. V. Quynh, V. T. P. Thao, and L. Q. Duy, "Optimal design parameters of air suspension systems for semi-trailer truck. Part 1: modeling and algorithm," *Vibroengineering PROCEDIA*, Vol. 33, pp. 72–77, Oct. 2020, https://doi.org/10.21595/vp.2020.21562

[14] N. V. Tuan, L. V. Quynh, V. T. P. Thao, and L. Q. Duy, "Optimal design parameters of air suspension systems for semi-trailer truck. Part 2: results and discussion," *Vibroengineering PROCEDIA*, Vol. 33, pp. 147–152, Oct. 2020, https://doi.org/10.21595/vp.2020.21563

[15] ISO 2631-1. Mechanical Vibration and Shock-Evaluation of Human Exposure to Whole-Body Vibration, Part I: General Requirements. The International Organization for Standardization, 1997

[16] ISO 8608. "Mechanical Vibration-Road Surface Profiles-Reporting of Measured Data". *International Organization for Standardization*, 2016.

Tran Duc Hoang received bachelor's degree in Thai Nguyen University of Technology, Viet Nam in 2010. Now he is a teaching assistant at the Department of Automotive Engineering, Faculty of Vehicle and Energy Engineering, Thai Nguyen University of Technology, Viet Nam. His current research interests include Vehicle dynamics, Vehicle vibration and noise, Optimal design and control.

Nguyen Thi Hong Ngoc received bachelor's degree in Hanoi University of Industry, Viet Nam in 2019. Now she is a teaching assistant at the Department of Automotive Engineering, Faculty of Vehicle and Energy Engineering, Thai Nguyen University of Technology, Viet Nam. Her current research interests include Electric vehicle technology, Electric vehicle battery, Optimal design and control.

Le Van Quynh received his Ph.D. degree in School of Mechanical Engineering, Southeast University, China in 2013. Now he is an Associate Professor at the Department of Automotive Engineering, Faculty of Automotive and Power Machinery Engineering, Thai Nguyen University of Technology, Viet Nam. His current research interests include Vehicle dynamics, Vehicle vibration and noise, Optimal design and control.

Nguyen Dinh Tan received his Ph.D. degree in Hanoi University of Science and Technology, Viet Nam in 2018. Now he is a lecturer in Faculty of Mechanical Engineering, East Asia University of Technology, Bac Ninh, Vietnam. His current research interests include Manufacturing technology, Lubricating and cooling, Vehicle dynamics, Optimal design and control

The Minh Huong received Master's degree in University of Transport and Communications, Viet Nam in 2011. Now he is a lecturer in Viet Nam – Korea College of Quang Ninh, Quang Ninh, Vietnam. His current research interests include Vehicle dynamics, Vehicle vibration and noise, Optimal design and control