ISSN: 0974-5823 Vol. 7 No. 1 January, 2022

International Journal of Mechanical Engineering

Improving the Performance of the Vehicle Suspension System Using Inerter

Dawood Saleem Hannoot Allami*, Waleed Khaled Alashtari
Mechanical Engineering Department, University of Baghdad/College of Engineering, Wasit/ Iraq

Abstract:

This paper investigates the effect of adding Inerter on the enhancing the performance of the suspension system which leads to increasing the comfort of vehicle rides, stability of handling and driving safety. A new vehicle suspension system known as ISD suspension, consists of the inerter, damper and spring has been developed. A suspension system of the quarter vehicle model was mathematically modeled, where, it consists of a sprung mass, unsprung mass, inerter, damper and spring. The inerter is added in parallel to spring and damper. Solve equation of the ISD suspension system by using simulation in MATLAB/SIMULINK and simulation the models of the suspension system by using ANSYS WORKBENCH 2019 R3. Compare the results of the ISD suspension system with traditional passive suspension system, where displacement of the sprung mass decreases by 20.4 %. Acceleration of the of the sprung mass decreases with value of 10.2%. The displacement of the unsprung mass increases by 14.2% also and the acceleration increases by value 51%. Using ANSYS WORKBENCH R2019 programmer to simulation effect of the inerter, where found out the results of the analytical solution by MATLAB is identical or close to the results of numerical simulations by means of the ANSYS WORKBENCH. The optimal parameters of the inerter are obtained. Found that, the performance of the inerter decreases with increasing the value of the pitch screw of the inerter and increases with increasing the value of the flywheel mass. The displacement of the sprung mass decreases with magnitude of reductions of 5 %, 7.7 %, 16.5 % and 24.7 % with values of the screw's pitch are 40, 30, 20 and 10 mm respectively. The value of the acceleration of the sprung mass system decreases with increasing the value of the pitch, where decreases with magnitude of reduction of 16.5 %, 33 %, and 60 % with value of the screw's pitch with 40, 30 and 20 mm respectively but when the value of the pitch 10 mm reaches, we notice that the value of the acceleration begins to increase with 28% more the acceleration of the passive suspension. The displacement and acceleration of the sprung mass decrease with increasing mass of the inerter's flywheel, where the displacement decreases with magnitude of reduction of 9%, 16% and 19.6% and 21.8% with value of the mass flywheel with 0.5, 1, 1.5 and 2 kg respectively. The value of the acceleration decreases with magnitudes of reduction of 39.2 %, 64%, and 34.5 %, 13.9% with masses of the inerter's flywheel are 0.5, 1, 1.5 and 2 kg respectively.

Keywords : Suspension system, Inerter, Sprung mass, Unsprung mass, Inertance, MATLAB/SIMULINK, ANSYS WORKBENCH

Introduction:

The suspension system is the most important component of the vehicle, since it directly affects vehicle's driving safety, ride comfort of passengers and the vehicle's road keeping capability, which is important for the protection and stability of the system by isolating the vehicle's body from shocks caused by uneven road profiles, engine movements, drag forces and non-uniform wheel/tire dimensions. Maintaining vibrations over long periods of time can lead to some problems, such as discomfort for travelers. To mitigate these issues, momentary loads imposed by the ground can be absorbed and dissipated. Suspension systems in automobiles are designed to withstand and reduce shocks and vibrations transmitted from the road to the passengers and the vehicle's chassis. Suspension systems for automobiles are divided into three types: passive, semi-active, and active system. Passive automotive suspensions are modeled in Fig.1 is a conventional mechanical suspension configuration that consists of vicious damper and linear stiffness with damping coefficient and constant stiffness [1]. Passive suspension is dependable, uncomplicated, and affordable. The spring and damper are attached between the car's body and structure that supports the wheels. The interior of a damper is filled with hydraulic fluid or compressed gas, and a piston is attached to the exterior through a rod. The movement of a piston is allowed by a hole that enables fluid to flow between cylinder components. This fluid flow produces a reactional force that is equal to the difference in speed between the unsprung and sprung masses. The damping effect is then achieved by transforming the energy of the oscillations to heat. This uncomplicated suspension system is incapable of producing acceptable results for resolving suspension issues because it lacks external regulation and feasible improvements in terms of components, hole valves, and even shapes [2]. Semi-active suspensions are similar to passive suspensions with the only exception being that the damping coefficient is variable but the spring stable remains constant, as well as the lack of active force sources [3] with the only exception being that the damping coefficient is variable but the spring constant remains constant, and that sources of active force are not present. This type of device enables smooth transitions between passive and semi-active damping coefficients. In comparison to previous suspension systems, an active system incorporates an actuator capable of supplying active force that is controlled by a regulating algorithm that utilizes data from attached vehicle sensors [4]. active suspension may consist of an actuator, damper and mechanical spring, and; or it may consist only of a mechanical spring and actuator. Since the dampers and springs are controlled by an actuator power, these systems have significantly improved reaction capability when confronted with induced vertical forces triggered by unexpected changes in road input. Active isolation systems are more complicated, expensive and difficult. Passive isolation systems are favorable in a wide variety of practical applications due to their flexibility, durability, robustness, and low cost. As mentioned earlier, it consists of linear springs which stores system's energy and viscous damper a that dissipates system's energy in order to achieve vibration isolation. Recently, a new form of automobile suspension was introduced that utilizes an inerter [5] has attracted scholars' interest. It is capable of converting linear motion to flywheel rotation which produces a significant amount of inertial mass in comparison to the flywheel's gravitational mass. In the mechanical-electrical analogy, the spring, damper and mass correspond to the, inductor, resistor and capacitor [6]. However, the analogy is not complete since mass is an element with a single terminal. To complete the analogy, a flywheel can be used to obtain a double-terminal mass [7], [8], that results in the formation of a new suspension feature dubbed the inerter. The efficiency of the conventional mechanical spring-damper system can be increased and has been commonly used in automotive suspensions [9], [10], [11],[12] train suspensions [13], [14], building suspensions [15] and the compensation for steering on high-performance bikes [16]. There are three types of inerter, rack pinion inerter [5], ball screw inerter [17] and hydraulic inerter [18]. Additionally, it can be divided into two categories depending on whether a flywheel is included in the realization, that is inerters that use a flywheel and inerters that do not use a flywheel. However, the backlash and the friction between the gears significantly amplify the inerter's nonlinearities. The ball screw inerter, which is the second generation of inerters. In comparison to the rack-pinion inerter, friction is significantly decreased, and backlash can be avoided entirely by pre-loading. In this study, improve performance of the passive suspension system using ball screw inerter, where it reduces the vertical displacement and acceleration of the sprung mass. Constructing a physical model that accurately represents the suspension system with ball screw inerter based dynamic equations. A fourth vehicle model is used to described the suspension system. Deriving a mathematical model of the inerter to study the parameters that affect the amount of the inerter constant, the amount of this constant determines the amount of improving of the suspension system. The theoretical work described previously has been validated using MATLAB-Simulink and by using ANSYS workbench. Experimental investigation of suspension system. Additionally, a basic laboratory approach may be used to determine the proposed structure's damping and stiffness.

2. Theoretical modelling of the suspension system:

In this study the suspension system is modeled as a quarter automobile with tow degrees of freedom to simplify the issue and analyze only the vertical motion of a vehicle. The model and parameters of the passive suspension system are seen in the figure (1). From above, m_s is a quarter mass of a vehicle body (sprung mass). The vehicle suspension comprises the spring (k_s) and the damper (c_s). $m_u$represents mass of the tire and wheel (unsprung mass). The damper (c_t) and spring (k_t) are used to model the tire. y_r , y_u, y_s represent the road disturbance, the displacement of the unsprung mass and sprung mass respectively. To model this system mathematically, the law of Newton will be used to each mass. The dynamic equations of the passive suspension system as follow for the sprung mass (m_s)

$$m_s \frac{d^2 y_s}{dt^2} = k_s(y_u - y_s) + c_s(\frac{dy_u}{dt} - \frac{dy_s}{dt}) \tag{1}$$

For the unsprung mass (m_u)

$$m_u \frac{d^2 y_u}{dt^2} = -k_s(y_u - y_s) - c_s(\frac{dy_u}{dt} - \frac{dy_s}{dt}) + k_t(y_r - y_u) + c_t(\frac{dy_r}{dt} - \frac{dy_u}{dt}) \tag{2}$$

Inerter with constant (b) which are paired in parallel with spring (k_s) and damper (c_s) as shown in figure (2). The dynamic model of the Suspension system with inerter ISD, where b represents inertance of the inerter. The dynamic equations of ISD system are given by:

$$m_s \frac{d^2 y_s}{dt^2} = k_s(y_u - y_s) + c_s(\frac{dy_u}{dt} - \frac{dy_s}{dt}) + \mathrm{b}(\frac{d^2 y_u}{dt^2} - \frac{d^2 y_s}{dt^2}) \tag{3}$$

$$m_u \frac{d^2 y_u}{dt^2} = -k_s(y_u - y_s) - c_s(\frac{dy_u}{dt} - \frac{dy_s}{dt}) - \mathrm{b}(\frac{d^2 y_u}{dt^2} - \frac{d^2 y_s}{dt^2}) + k_t(y_r - y_u) + c_t(\frac{dy_r}{dt} - \frac{dy_u}{dt}) \tag{4}$$

Where $(\frac{dy_s}{dt})$ and $(\frac{d^2y_s}{dt^2})$ represent velocity and acceleration of the sprung mass, $(\frac{dy_u}{dt})$ and $(\frac{d^2y_u}{dt^2})$ represent velocity and acceleration of the unspurng mass.

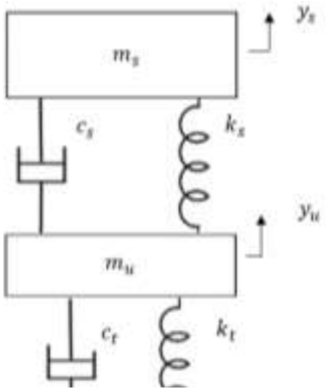

Figure (1) passive suspension system

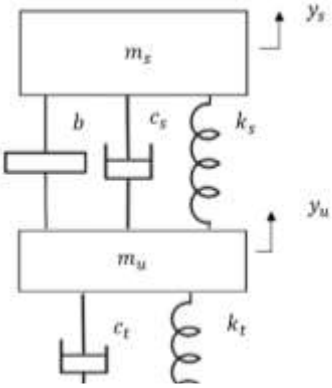

Figure (2) ISD suspension system

3. Theoretical modelling of the inerter

The ball screw inerter's structural design, which primarily consists of screw, nut and flywheel, as shown in figure (3). The inertance of the ball-screw inerter may be calculated from this equation [27]

$$b = (\frac{2\pi}{p})^2 I_f \qquad (5)$$

Where b is the constant of the inerter (inertance), p is the pitch of the screw and I_f is the flywheel's mass moment of inertia. The pitch of the inerter's screw, the mass of the inerter's flywheel and the radius of the inerter's flywheel are 20 mm. 1.5 kg and 11.8 cm respectively. From the relations (5), the value of the inertance is 250 kg. In this paper changing parameter of the ball screw inerter to study its influence on the performance of the inerter.

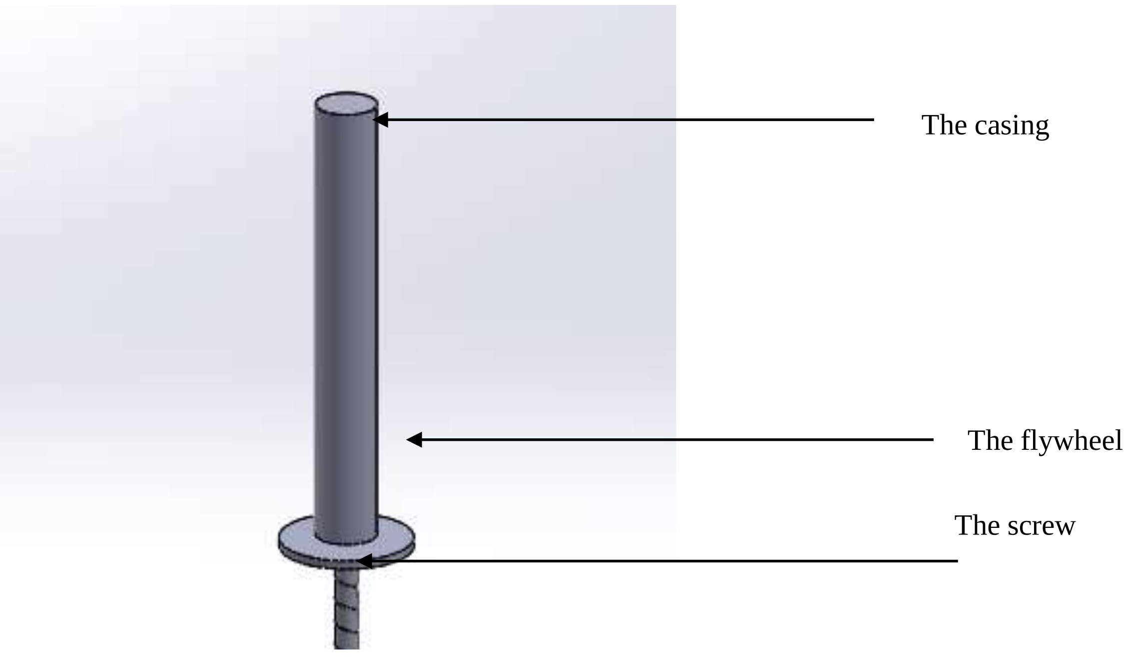

Figure (3) The model of ball screw inerter

4. Theoretical analysis of the vehicle suspension system using MATALB SIMULINK

Using the mathematical blocks provided in MATLAB SIMULINK, do an analysis based on the dynamic equations of the suspension system of the quarter car model to analyze the effect of the inerter on the response of the suspension system as shown in figures (4 and 5). The table below shows the analysis's input parameters of the model.

Table 1. Input parameters

S.NO	Parameter	Value
1	Sprung mass m_s	118 kg
2	Un sprung mass m_u	30 kg
3	Stiffens of suspension spring, k_s	100000 N/m
4	Coefficient of suspension damping c_s	1000 N.s/m
5	Tire stiffness, k_t	200000 N/m
6	Tire damping coefficient, c_t	2000 N.s/m
7	The value of the inertance, b	250 kg

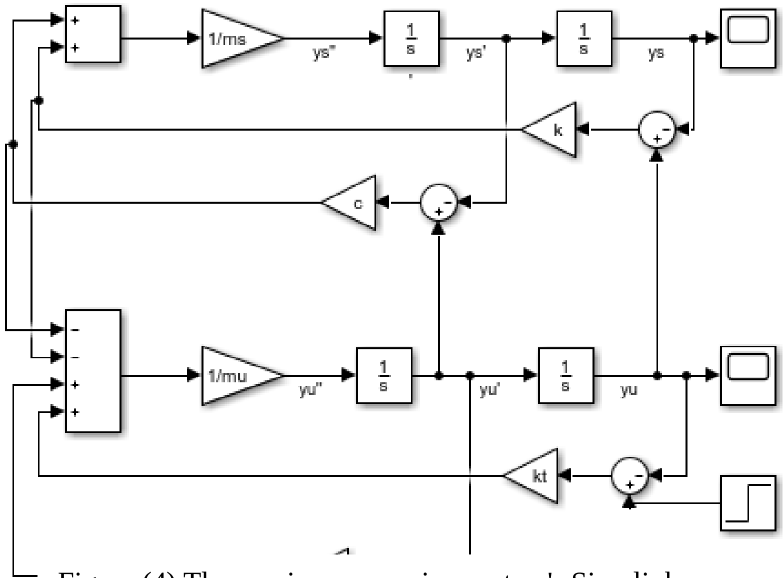

Figure (4) The passive suspension system's Simulink

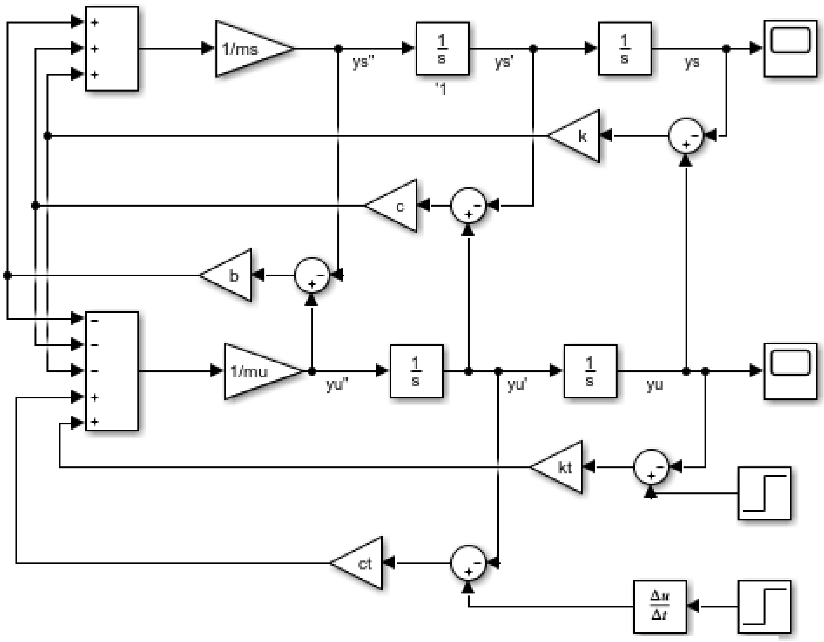

Figure (5) The ISD suspension system's Simulink model

5. Numerical analysis of the vehicle suspension system using ANSYS WORKBENCH

In this section, provides numerical analyses that were created to verify the theoretical work. Design model of the inerter by Soildwork programming with Detailed design that accounts for functional components of the ball-screw inerter is created, as is show in figure (3). Using the ANSYS-WORKBENCH 2019 R3 to build the numerical model of passive suspension system of the vehicle the suspension system and suspension system with inerter (ISD), as shown in figures (6 and 7). Simulation of the designed models to study the effect of the inerter on the response of the suspension system. Investigated optimum parameters such as pitch of the screw's inerter and mass of the flywheel's inerter, that affects performance of the inerter.

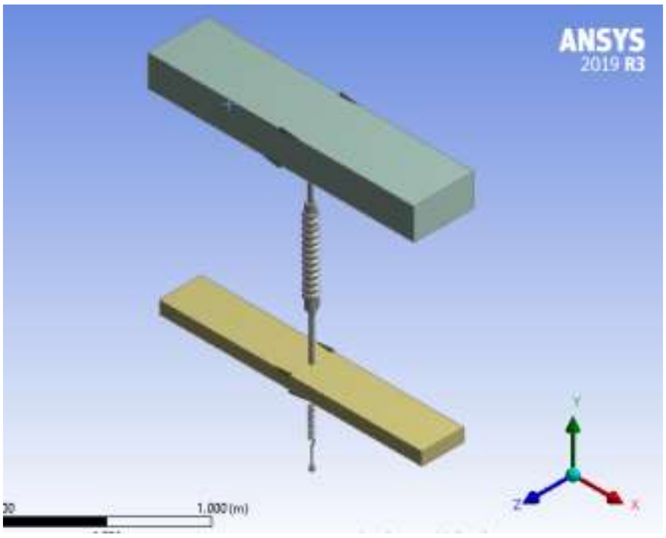

Figure (6) Model of the passive suspension system

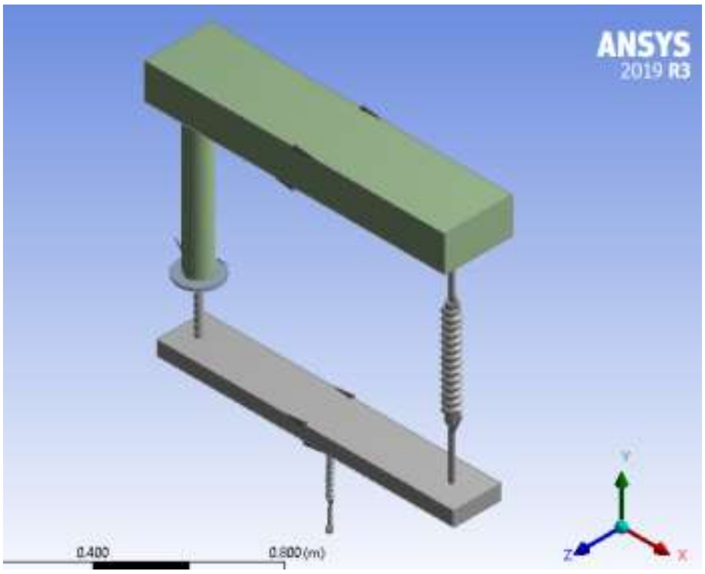

Figure (7) Model of the ISD suspension system

6. The Effect of the Inerter on the Response of the Vehicle Suspension System

Figure (8) represents the results of analysis by MATLAB/Simulink and figure (9) represents the results of analysis by ANSYS Workbench. We note from the below pictures that the theoretical and numerical results are identical. The figures show influence of the inerter on the displacement and the acceleration of the sprung mass. The value of inertance 250 kg and step input 0.11 m (rod disturbance). The value of sprung mass displacement decreases due to adding inerter lead to changing the inertia of the system. It can significantly reduce sprung displacement, with magnitude reduction of 20.4 % compared to a passive system that does not include an inerter. A further reduction in the displacement of the sprung mass can be achieved by increasing the inertance. Also, acceleration of the sprung mass system decreases with 10.2%.

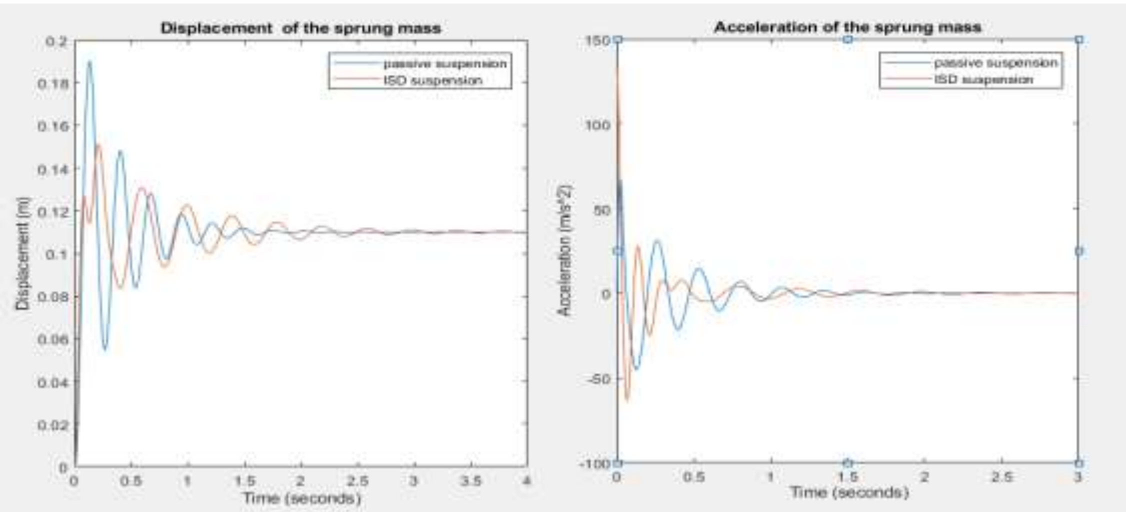

Figure (8) Response of the sprung mass by MATLAB/Simulink

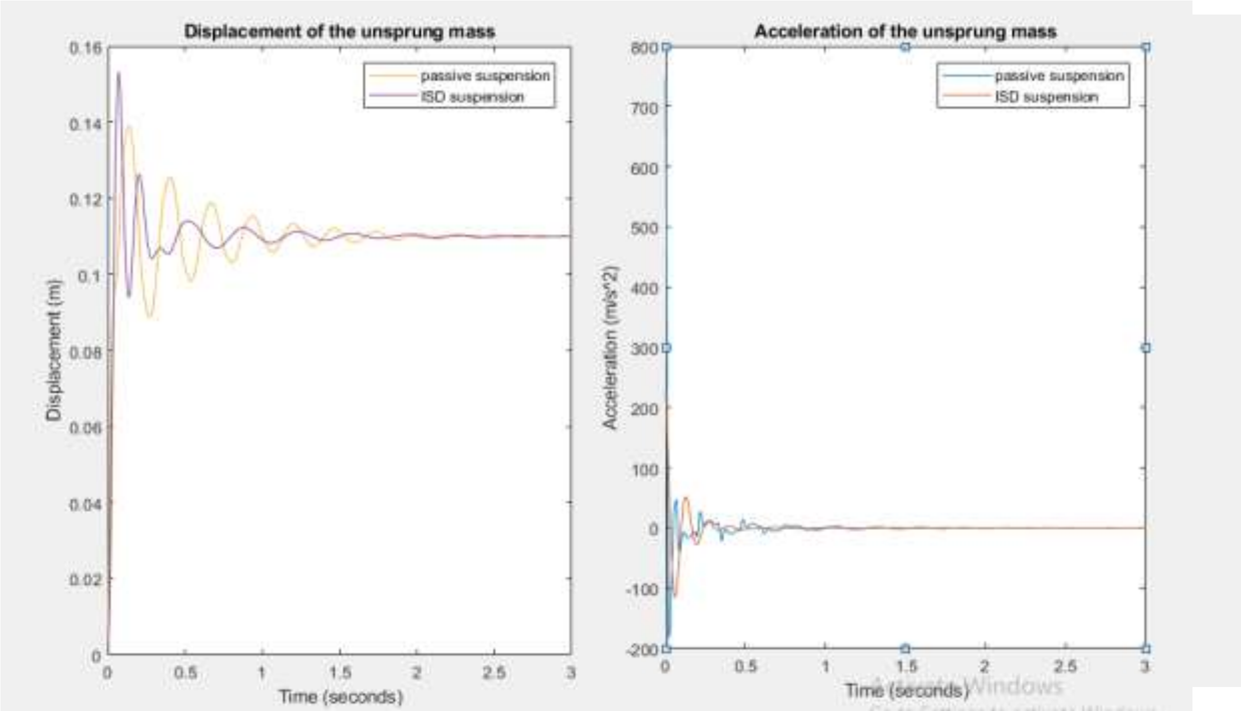

Figure (9) Response of the sprung mass by ANSYS Workbench

Influence of the inerter on the displacement and acceleration of the unsprung mass with step input 0.11 m as shown in figures (10 and 11). The displacement and acceleration of the unsprung mass increases when adding the inerter with the inertance is 250 kg with 14.2 and 51% respectively. This increasing due to, the effect of the inerter on the unsprung mass is opposite to the effect of the inerter on the sprung mass, and this is clear from the equations 3 and 4.

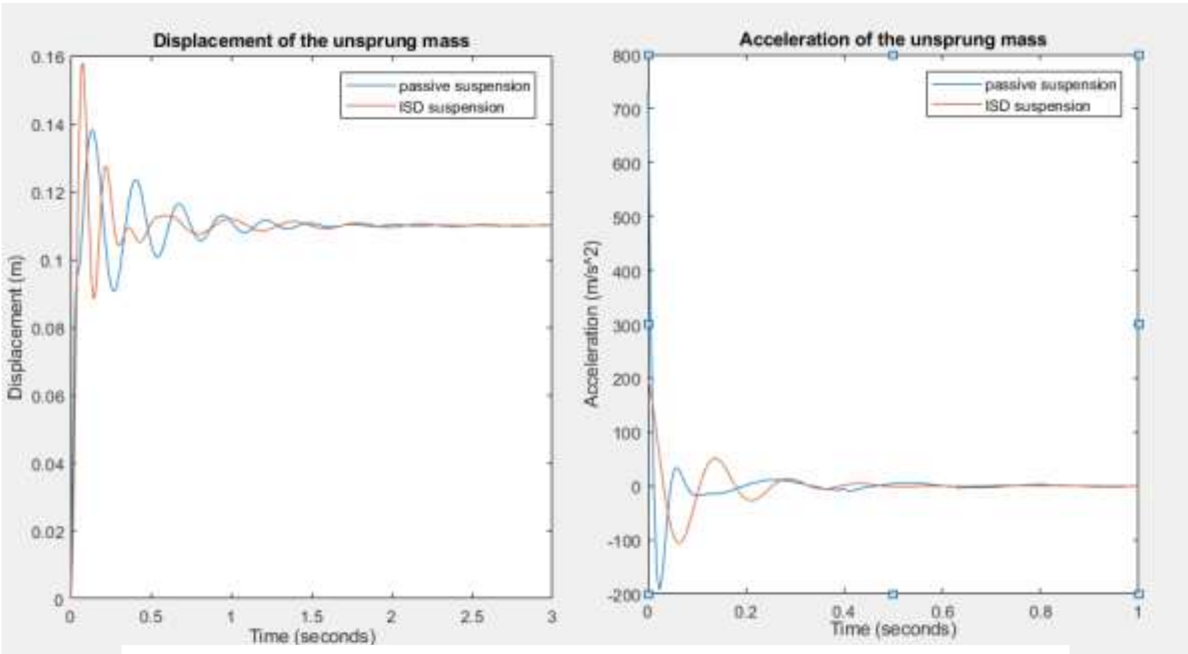

Figure (10) Response of the unsprung mass by MATLAB/Simulink

6.2 of The Figure (11) Response of the unsprung mass by ANSYS Workbench **Parameters Optimization Inerter:**

The ball screw's parameters including pitch of screw, diameter of the flywheel, and mass of the flywheel are optimized during simulation to investigate its effect on the performance of the inerter.

Firstly, the pitch of the screw is changed and other parameters are unchanged. Figures (12 and 13) shows the displacement and the acceleration of the sprung mass of variable pitch of the inerter's screw. It can be shown that both the displacement of the sprung mass decreases with decreasing the pitch, this is according to the following Law of the inertance($b = (\frac{2\pi}{p})^2 \mathrm{I_f}$) or in other words, number of flywheel rotations to a given distance increases with decreasing the pitch of the screw, thus increase the. kinetic energy absorbed by the flywheel. The displacement decreases with magnitude of reductions of 5 %, 7.7 %, 16.5 % and 24.7 % with values of the screw's pitch are 40, 30, 20 and 10 mm respectively. The value of the acceleration of the sprung mass system decreases with increasing inertance of the inerter. The acceleration decreases with magnitude of reduction of 16.5 %, 33 %, and 60 % with value of the screw's pitch with 40, 30 and 20 mm respectively but when the value of the pitch 10 mm reaches, we notice that the value of the acceleration begins to increase with 28%. More than acceleration of the passive suspension.

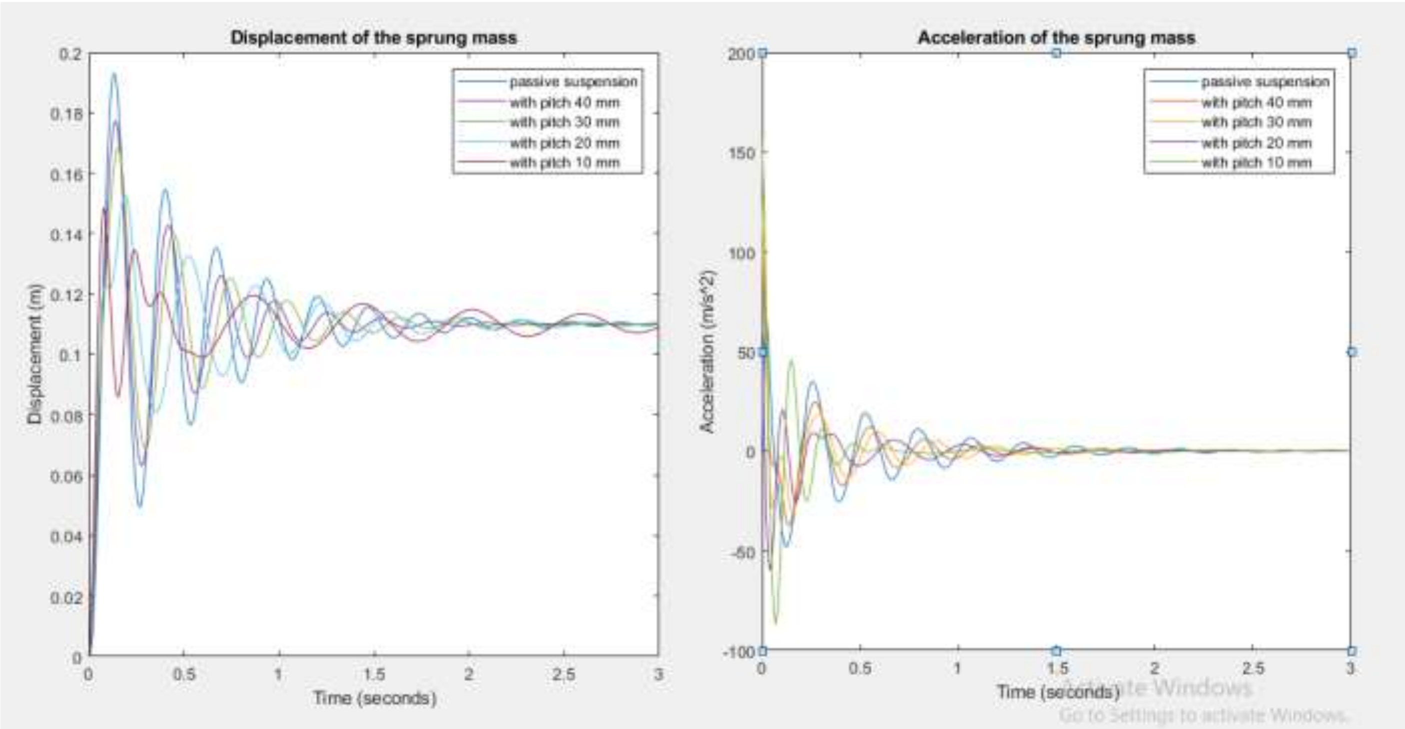

Figure (12) Changing of the sprung mass's response with changing of the pitch by MATLAB/Simulink

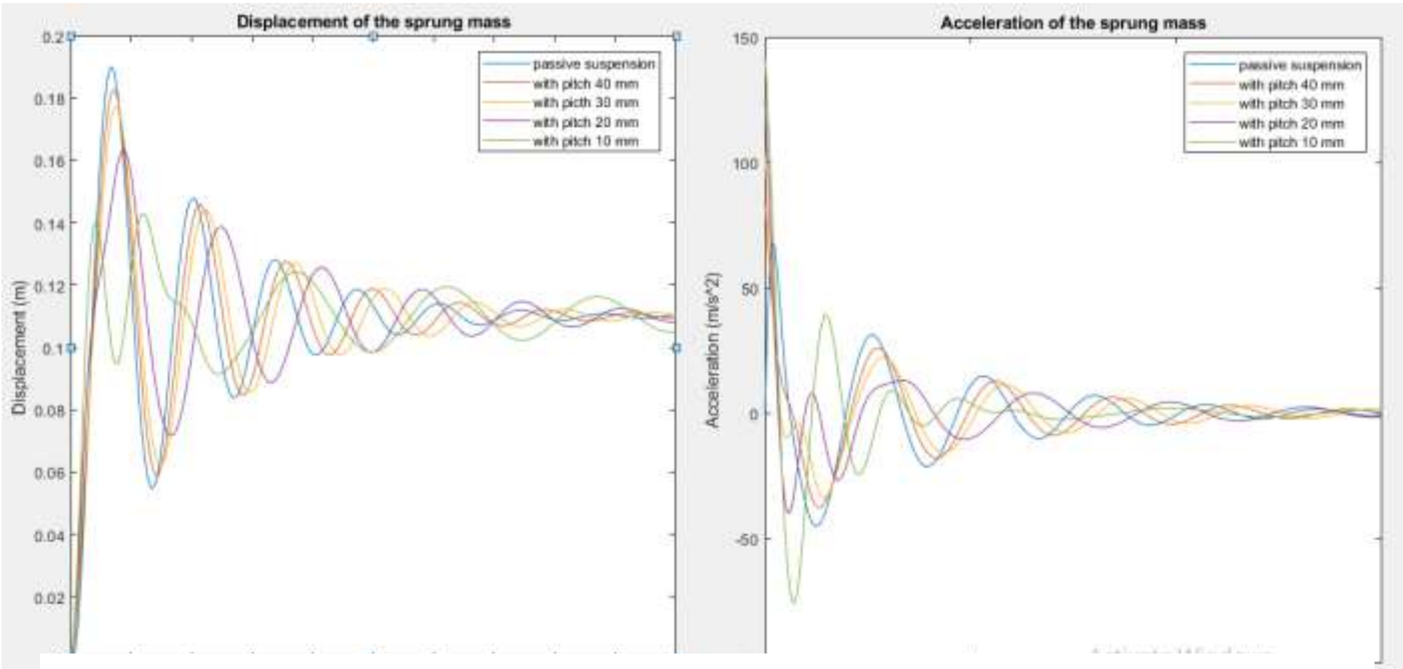

Figure (13) Changing of the sprung mass's response with changing of the pitch by ANSYS Workbench

Secondly, the mass of the flywheel is changed and other parameters are unchanged. Figures (14 and 15) shows the displacement and acceleration of the sprung mass decrease with increasing mass of the inerter's flywheel, where the displacement decreases with magnitude of reduction of 9%, 16% and 19.6% and 21.8% with value of the mass flywheel with 0.5, 1, 1.5 and 2 kg respectively. This reduction, as mentioned earlier due to the increase value of the mass will increase the value of the inertance of the inerter. The value of the acceleration decreases with magnitudes of reduction of 39.2 %, 64%, and 34.5 %, 13.9% with masses of the inerter's flywheel are 0.5, 1, 1.5 and 2 kg respectively.

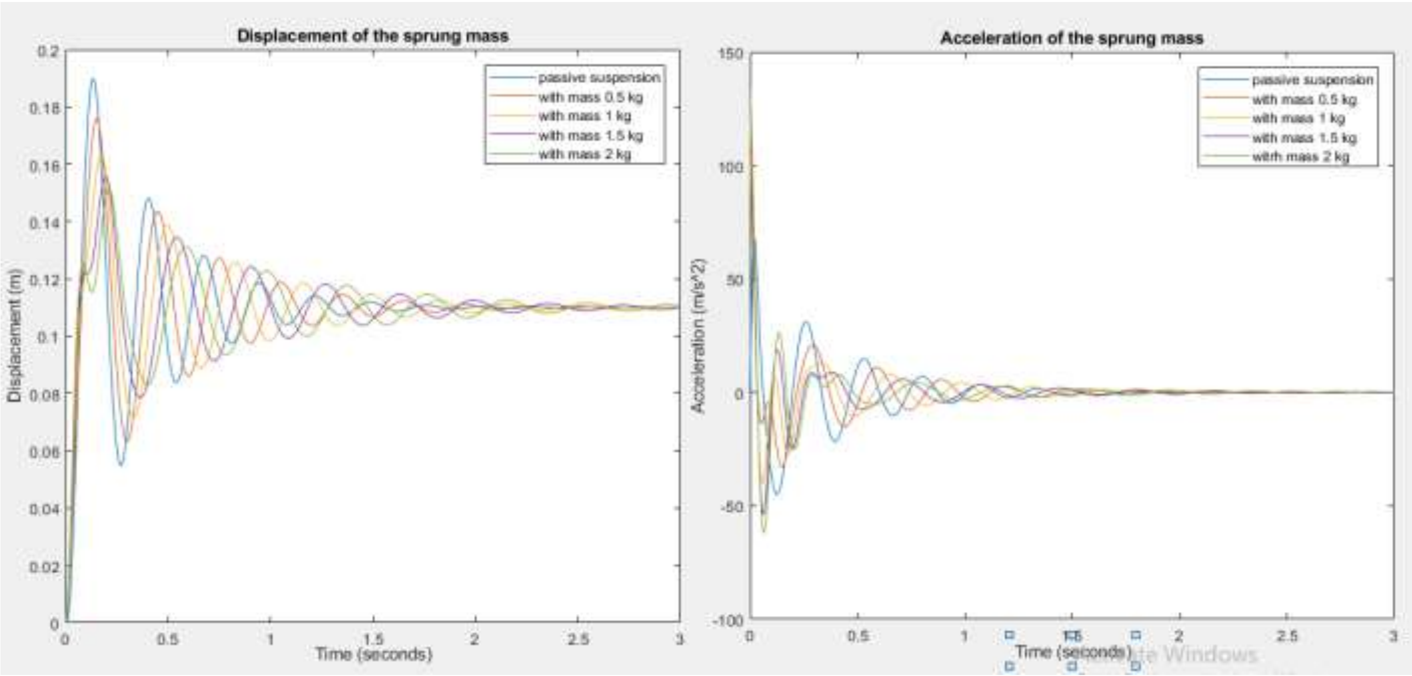

Figure (14) Changing of the sprung mass's response with changing value of mass by MATLAB/Simulink

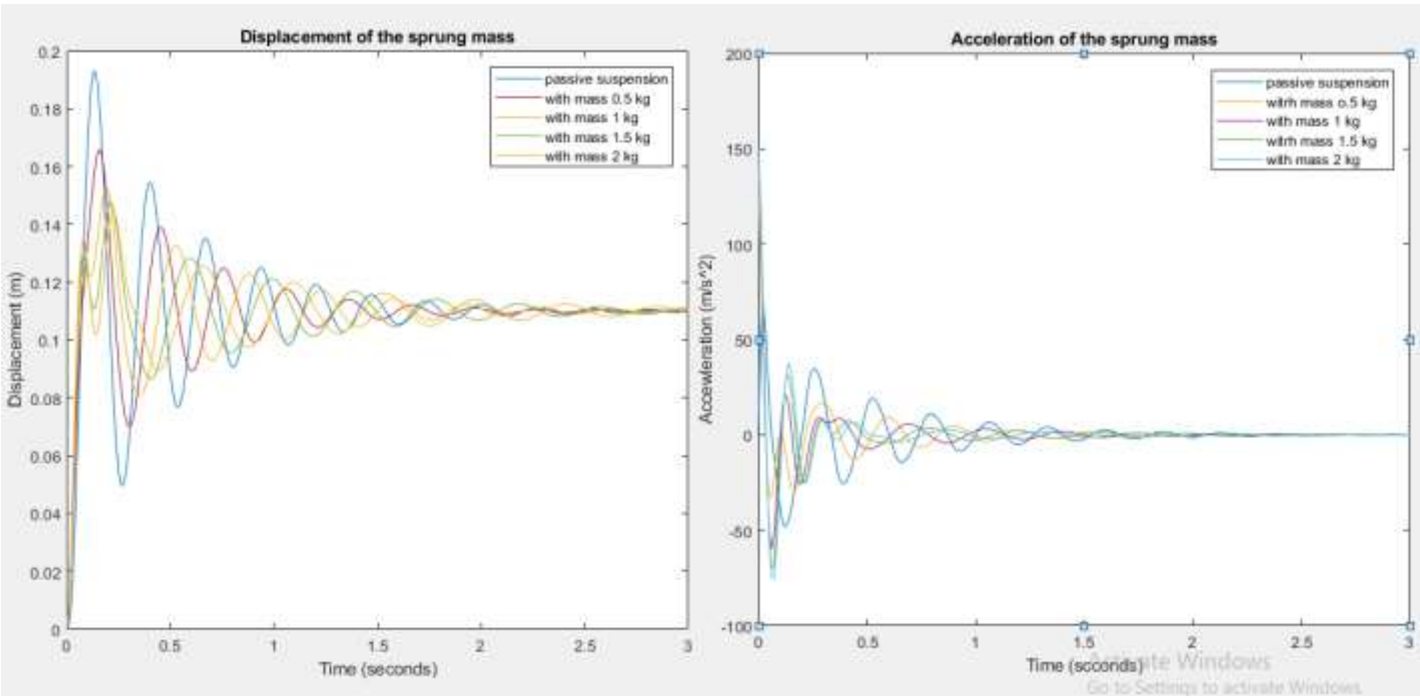

Figure (15) Changing of the sprung mass's response with changing value of mass by ANSYS Workbench

7. Conclusions

In this paper investigates improving the performance of the vehicle suspension system using ball screw inerter to get new suspension system (ISD). Both theoretical and numerical analysis demonstrate that adding inerter could lead to improvement in the performance of the vehicle suspension system. The displacement and the acceleration of the sprung mass can be decreased by 20.4%

and 10.2% respectively. But the displacement and the acceleration of the unsprung mass can be increased by 14.2% and 51% respectively.
Found that, the performance of the inerter can be decreases with increasing the value of the pitch screw of the inerter, where the displacement of the sprung mass can be decreased by 5 %, 7.7 %, 16.5 % and 24.7 % with values of the screw's pitch are 40, 30, 20 and 10 mm respectively. The value of the acceleration of the sprung mass system can be decreased by 16.5 %, 33 %, and 60 % with value of the screw's pitch with 40, 30 and 20 mm respectively but when the value of the pitch 10 mm reaches, noted that the value of the acceleration began to increased more than acceleration of passive suspension. The displacement and acceleration of the sprung mass can be decreased with increasing mass of the inerter's flywheel, where the displacement can be decreased by 9%, 16% and 19.6% and 21.8% with values of the mass flywheel are 0.5, 1, 1.5 and 2 kg respectively. The value of the acceleration can be decreased by 39.2 %, 64%, and 34.5 %, 13.9% with masses of the inerter's flywheel are 0.5, 1, 1.5 and 2 kg respectively.

References

[1] A. Perescu and L. Bereteu, "Simulation and comparison of quarter-car passive suspension system with Bingham and Bouc-Wen MR semi-active suspension models," *AIP Conf. Proc.*, vol. 1564, no. 2013, pp. 22–27, 2013, doi: 10.1063/1.4832791.

[2] I. Martins, J. Esteves, F. P. da Silva, and P. Verdelho, "Electromagnetic hybrid active-passive vehicle suspension system," *IEEE VTS 50th Veh. Technol. Conf. VTC 1999-Fall*, vol. 3, pp. 2273–2277, 1999, doi: 10.1109/vetec.1999.778470.

[3] R. Wang, X. Meng, D. Shi, X. Zhang, Y. Chen, and L. Chen, "Design and test of vehicle suspension system with inerters," *Proc. Inst. Mech. Eng. Part C J. Mech. Eng. Sci.*, vol. 228, no. 15, pp. 2684–2689, Oct. 2014, doi: 10.1177/0954406214521793.

[4] T. Yoshimura, A. Kume, M. Kurimoto, and J. Hino, "Construction of an active suspension system of a quarter car model using the concept of sliding mode control," *J. Sound Vib.*, vol. 239, no. 2, pp. 187–199, 2001, doi: 10.1006/jsvi.2000.3117.

[5] M. C. Smith, "Synthesis of mechanical networks: The inerter," *IEEE Trans. Automat. Contr.*, vol. 47, no. 10, pp. 1648–1662, 2002, doi: 10.1109/TAC.2002.803532.

[6] C. Papageorgiou, N. E. Houghton, and M. C. Smith, "Experimental testing and analysis of inerter devices," *J. Dyn. Syst. Meas. Control. Trans. ASME*, vol. 131, no. 1, pp. 1–11, 2009, doi: 10.1115/1.3023120.

[7] C. Li, S. Wang, L. Kang, S. Lei, and Q. Yu, "549. Two-terminal manipulation of masses: Application to vibration isolation of passive suspensions," *J. Vibroengineering*, vol. 12, no. 2, pp. 225–236, 2010.

[8] C. Li, M. Liang, Y. Wang, and Y. Dong, "Vibration suppression using two-terminal flywheel. Part I: Modeling and characterization," *JVC/Journal Vib. Control*, vol. 18, no. 8, pp. 1096–1105, 2012, doi: 10.1177/1077546311419546.

[9] M. C. Smith and F. U. C. Wang, "Performance benefits in passive vehicle suspensions employing inerters," *Veh. Syst. Dyn.*, vol. 42, no. 4, pp. 235–257, 2004, doi: 10.1080/00423110412331289871.

[10] C. Papageorgiou and M. C. Smith, "for Mechanical Networks : Application to Vehicle Suspension," *Control*, vol. 14, no. 3, pp. 423–435, 2006.

[11] A. Kuznetsov, M. Mammadov, I. Sultan, and E. Hajilarov, "Optimization of improved suspension system with inerter device of the quarter-car model in vibration analysis," *Arch. Appl. Mech.*, vol. 81, no. 10, pp. 1427–1437, 2011, doi: 10.1007/s00419-010-0492-x.

[12] Y. Shen, L. Chen, X. Yang, D. Shi, and J. Yang, "Improved design of dynamic vibration absorber by using the inerter and its application in vehicle suspension," *J. Sound Vib.*, vol. 361, pp. 148–158, 2016, doi: 10.1016/j.jsv.2015.06.045.

[13] H. J. Chen, W. J. Su, and F. C. Wang, "Modeling and analyses of a connected multi-car train system employing the inerter," *Adv. Mech. Eng.*, vol. 9, no. 8, pp. 1–13, 2017, doi: 10.1177/1687814017701703.

[14] F. C. Wang and M. K. Liao, "The lateral stability of train suspension systems employing inerters," *Veh. Syst. Dyn.*, vol. 48, no. 5, pp. 619–643, 2010, doi: 10.1080/00423110902993654.

[15] F. C. Wang, C. W. Chen, M. K. Liao, and M. F. Hong, "Performance analyses of building suspension control with inerters," *Proc. IEEE Conf. Decis. Control*, no. January, pp. 3786–3791, 2007, doi: 10.1109/CDC.2007.4434186.

[16] S. Evangelou, D. J. N. Limebeer, R. S. Sharp, and M. C. Smith, "Mechanical steering compensators for high-performance motorcycles," *J. Appl. Mech. Trans. ASME*, vol. 74, no. 2, pp. 332–346, 2007, doi: 10.1115/1.2198547.

[17] F. C. Wang and W. J. Su, "Impact of inerter nonlinearities on vehicle suspension control," *Veh. Syst. Dyn.*, vol. 46, no. 7, pp. 575–595, 2008, doi: 10.1080/00423110701519031.

[18] F. C. Wang, M. F. Hong, and T. C. Lin, "Designing and testing a hydraulic inerter," *Proc. Inst. Mech. Eng. Part C J. Mech. Eng. Sci.*, vol. 225, no. 1, pp. 66–72, 2011, doi: 10.1243/09544062JMES2199.

[19] Y. J. Shen, L. Chen, Y. L. Liu, X. L. Zhang, and X. F. Yang, "Improvement of the lateral stability of vehicle suspension

incorporating inerter," *Sci. China Technol. Sci.*, vol. 61, no. 8, pp. 1244–1252, 2018, doi: 10.1007/s11431-017-9228-0.

[20] Y. Hu, M. Z. Q. Chen, and Z. Shu, "Passive vehicle suspensions employing inerters with multiple performance requirements," *J. Sound Vib.*, vol. 333, no. 8, pp. 2212–2225, 2014, doi: 10.1016/j.jsv.2013.12.016.

[20] Y. Hu, M. Z. Q. Chen, and Z. Shu, "Passive vehicle suspensions employing inerters with multiple performance requirements," *J. Sound Vib.*, vol. 333, no. 8, pp. 2212–2225, 2014, doi: 10.1016/j.jsv.2013.12.016.

[21] K. Ramakrishnan, L. Yang, F. M. Ballo, M. Gobbi, and G. Mastinu, "Multi-objective optimization of road vehicle passive suspensions with inerter," *Proc. ASME Des. Eng. Tech. Conf.*, vol. 3, no. June 2017, 2016, doi: 10.1115/DETC2016-59864.

[22] G. Verros, S. Natsiavas, and C. Papadimitriou, "Design optimization of quarter-car models with passive and semi-active suspensions under random road excitation," *JVC/Journal Vib. Control*, vol. 11, no. 5, pp. 581–606, 2005, doi: 10.1177/1077546305052315.

[23] N. Alujević, D. Čakmak, H. Wolf, and M. Jokić, "Passive and active vibration isolation systems using inerter," *J. Sound Vib.*, vol. 418, pp. 163–183, 2018, doi: 10.1016/j.jsv.2017.12.031.

[24] X. SHI and S. ZHU, "A comparative study of vibration isolation performance using negative stiffness and inerter dampers," *J. Franklin Inst.*, vol. 356, no. 14, pp. 7922–7946, 2019, doi: 10.1016/j.jfranklin.2019.02.040.

[25] F. C. Wang and H. A. Chan, "Mechatronic suspension design and its applications to vehicle suspension control," *Proc. IEEE Conf. Decis. Control*, no. January 2009, pp. 3769–3774, 2008, doi: 10.1109/CDC.2008.4738900.

[26] A. Kuznetsov, M. Mammadov, I. Sultan, and E. Hajilarov, "Optimization of improved suspension system with inerter device of the quarter-car model in vibration analysis," *Arch. Appl. Mech.*, vol. 81, no. 10, pp. 1427–1437, 2011, doi: 10.1007/s00419-010-0492-x.

[27] X. Q. SUN[1)], L. CHEN[2)], S. H. WANG[1)], X. L. ZHANG[2)] and X. F. YANG[1)], "PERFORMANCE INVESTIGATION OF VEHICLE SUSPENSION SYSTEM WITH NONLINEAR BALL-SCREW INERTER," International Journal of Automotive Technology, Vol. 17, No. 3, pp. 399-408 (2016) DOI 10.1007/ s12239-016-0041-x.