JJMIE

Volume 11 Number 2, April. 2017
ISSN 1995-6665
Pages 67 -71

Jordan Journal of Mechanical and Industrial Engineering

A Laboratory Automotive Suspension Test Rig: Design, Implementation and Integration

Mohammad Salah

Dept. Mechatronics Engineering, Hashemite University, Jordan

Received Feb., 15, 2016 *Accepted Oct., 17, 2016*

Abstract

In the present paper, a laboratory test rig is designed and constructed at Hashemite University to study and analyze the effects of road terrains on automotive suspension systems. It is also used to study and analyze the nonlinear dynamic behavior of suspension systems. The proposed experimental suspension setup facilitates testing and validating various identification and controller designs. Hence, a useful educational, training, and research tool is introduced to emulate the effects of wide range of realistic road conditions on automotive suspension systems, while rapidly measuring, recording, and analyzing system variables. It should be noted that the focus of this paper is on the design and construction of a laboratory automotive suspension system test rig. Experimental testing is intended to be conducted in the future to practically demonstrate the performance of vehicular suspension under different operating modes.

Keywords: *Automotive suspension system, active and passive suspension, test rig, laboratory system*.

1. Introduction

Vehicles are typically equipped with hydraulic dampers and helical springs to isolate the car body from road irregularities and to ensure sufficient contact between tire and road. This will guarantee relatively sufficient safety and comfort for the passenger. Normally, comfort at a high level is desired which can be accomplished through reducing the vibration levels inside the car and simultaneously increasing the passenger's safety due to enhanced handling and ride stability. These performance specifications of a passenger car are mainly determined by the damping characteristic of the dampers. Passive dampers have a fixed damping characteristic determined by their design. Depending on the road excitation, however, it is desirable to adjust this characteristic to increase performance specifications. This leads to an increasing interest in active solutions. Semi-active and active suspension systems offer the possibility to vary the damper characteristics along with the road profile (e.g., by changing the restriction of one or more current controlled valves or by changing the viscosity of a magnetorheological fluid of the damper) [1]. In addition, active systems are able to supply mechanical power to each corner of the vehicle in order to dynamically adjust heave, roll and pitch motions [2, 3]. In fact, an active automotive suspension is some sort of hydraulic or pneumatic linear actuator that controls the vertical movement of the wheels relative to the chassis or vehicle body with an onboard system.

In recent years, the conception of active and semi-active suspension has been advanced, which gives a new way to improve the performance of suspension system. The adoption of active suspension system overcomes many defects of passive suspension, which can adapt the suspension system to its maximum extent under variable working conditions [4, 5]. However, there are some problems on actuator's responsive speed and fast realization of control strategy, such as structural complexity, expensive price, big volume, and heavy weight.

Active suspension system requires sensors to be located at different points of vehicle to measure the motions of the body, suspension system and/or the unsprung mass. This information is used in the vehicle controller to command the active suspension's actuator in order to provide the exact amount of force required. To meet above demands, novel vehicle passive and active suspensions were proposed and designed to allow experimental testing and analysis, such as [6, 7]. For example, the authors of [8] designed and developed a simplified and cost effective quarter car suspension test rig. They conducted an analytical analysis and experimental testing to validate the reliability of the test rig. In the last decade, many different active suspension system control approaches were developed [9–11]. The control approaches developed can be categorized into standard controllers (i.e., Proportional-Integral-Derivative (PID)) [12], linear [13], nonlinear [14], H-infinity [15], fuzzy logic [16], neural networks [17], optimal [18], and output feedback control techniques [19].

Usually, linear models are used for the design of suspension controllers. However, in order to analyze the influence of nonlinearities on the dynamic behavior, identification experiments can be conducted using a test rig to determine and identify the nonlinearities and

* Corresponding author e-mail: msalah@hu.edu.jo.

uncertainties associated with the suspension components (i.e., the nonlinearities of damper and tire, as well as the relevant friction effects) [20]. These data can be used to build a precise model of the suspension system in order to develop high performance active suspension controllers and to provide a simulation platform for the controller performance before Implementing on the test rig. In addition, fault diagnostics can be performed as in [21].

The proposed test rig can be used to ultimately investigate the effects and impact of various bumps and humps in roads, on the vehicle suspension, in addition to investigate the implementation of various control and identification algorithms. Moreover, the test rig can be used to study the effect of various road bumps/humps on a traditional passive and active suspension system and perform parametric study to obtain optimum running conditions. In other words, principles of competency- and research-based learning can be experienced [22].

The remainder of the present paper is organized as follows: Section 2 describes the design of the proposed suspension system, while Section 3 introduces the system components and sizing. In Section 4, the conclusion and future work are presented.

2. System Description and Design

As stated earlier, there is a need to have a laboratory test rig to study and analyze suspension systems in automotive applications. The main objective of having such laboratory test rig at Hashemite University is to enable students, trainees, and researchers to investigate various effects and impacts of road conditions on automotive suspension system throughout analyzing different measured variables. Hence, many sensors were mounted on the proposed test rig to acquire as much information as possible about the system dynamics. In addition, computer controlled actuators were utilized to emulate the road conditions. What proposed in the present paper is a realistic test rig (i.e., real scale for actual suspension system) to acquire and analyze real data for actual vehicles. In the literature, few test rigs to investigate the performance of suspension systems were found and few researches really tested a quarter car model (e.g., [2], [6], [11], [17]). Most designs that tested suspension systems incorporated the entire vehicle.

The proposed laboratory system consists of a frame that could easily fit through standard dimensioned doors and moved about for display purposes (i.e., a base of 2.0 x 1.5m with a height of 1.8m). Criteria imposed on the test rig include reasonable compact size of design to allow for easy storage and transportation as shown in Figure 1.

The suspension system is designed to handle a maximum weight of 300kg that should be equivalent to a quarter car. Various bumps and humps can be emulated by exciting the suspension system in order to simulate forces and movements on a wheel with frequencies up to 10Hz and to simulate the vehicle running up to a speed of 162km/h (i.e., the wheel rotates at a rate of about 1250RPM given its dimensions as 205/75R15). The wheel excitation mechanism is designed to provide a maximum amplitude of 10cm at different frequencies. The proposed system is designed to emulate the actual road behavior of the suspension with the wheel rotating and vertically moving up and down. The LabVIEW developing software tool is utilized to acquire data obtained from sensors within the test rig and to control the actuators of the proposed suspension system.

The proposed test rig utilizes a servo system with a rotary AC motor coupled to a screw with a suitable pitch distance to excite the suspension system by generating a linear motion. The advantage of using a servo motor is to get a precise performance in terms of position and speed. On the other side, the angular speed of the wheel is controlled by an AC motor that is controlled by an inverter.

In addition, a 100bar hydraulic unit is installed in the test rig to operate the active suspension (two inlets/outlets hydraulic cylinder). The hydraulic unit with manually adjustable internal pressure mainly features an oil tank with its pressure relief valve, hydraulic pump, a 4/3 way directional hydraulic double valve with mid-way closed block, and two inlets/outlets hydraulic cylinder to serve as the active suspension.

A lot of sensors are inserted and mounted in different places in the proposed automotive suspension test rig to ensure capturing all possible variations in the system variables while operation. Installed sensors include two linear encoders, one rotary shaft encoder, wheel pressure sensor with display, and two accelerometers. The hydraulic unit consists of pressure, flow, and temperature sensors. Figure 2 shows a representative block diagram for the proposed suspension test rig.

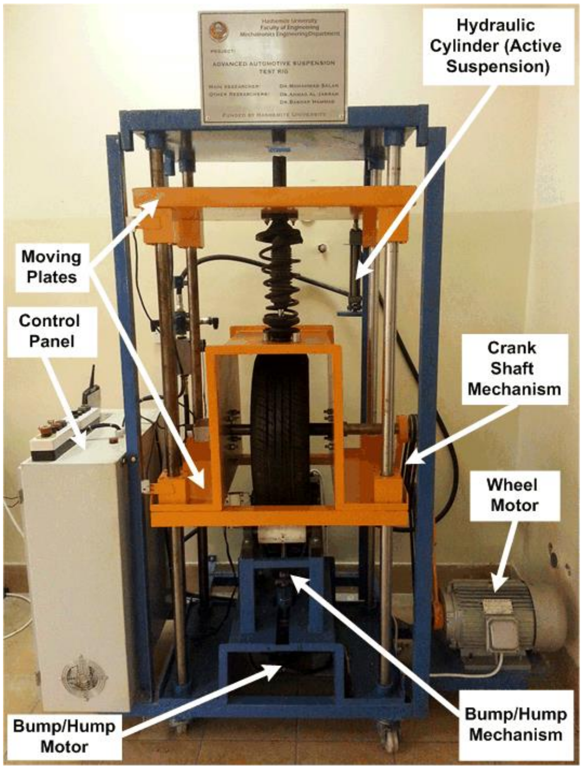


Figure 1. Automotive suspension test rig.

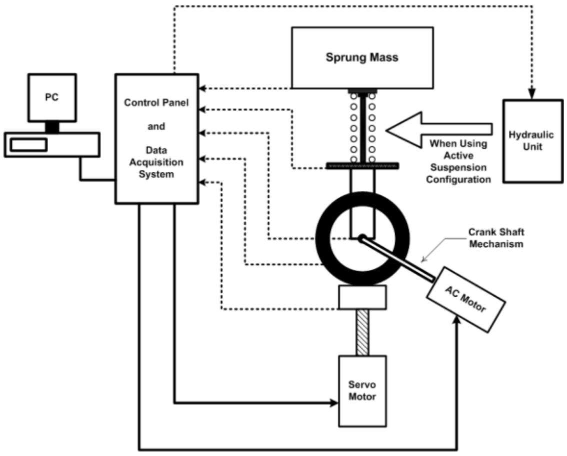


Figure 2. The automotive suspension test rig block diagram.

3. System Components and Sizing

The proposed automotive suspension system is designed and scaled to match a real quarter car so that realistic performance can be investigated and realistic data analysis can be conducted.

A. Mechanical Structure

The proposed automotive suspension test rig has two free-to-move plates; one at the top and one at the bottom as shown in Figure 1. The top plate represents quarter of the vehicle body and it carries the vehicle wheel via the suspension components (*i.e.*, spring and damper). The bottom plate is attached to the wheel to facilitate mounting and installing the suspension components. Both plates are guided by four stainless steel rods to ensure that suspension mechanism moves vertically with no torsion. The two plates are made of steel and the four bars are made of stainless steel of almost 1.8m height and diameter of 5cm, coated with chrome to make the movement of the plates easier. In addition, to enhance the easiness of plates' motion with less friction, axial bearings are mounted on the plates. A crank shaft mechanism assisted with pulleys and belts was utilized to keep the wheel rotating while moving vertically due to external emulated bumps and humps as shown in Figure 3.

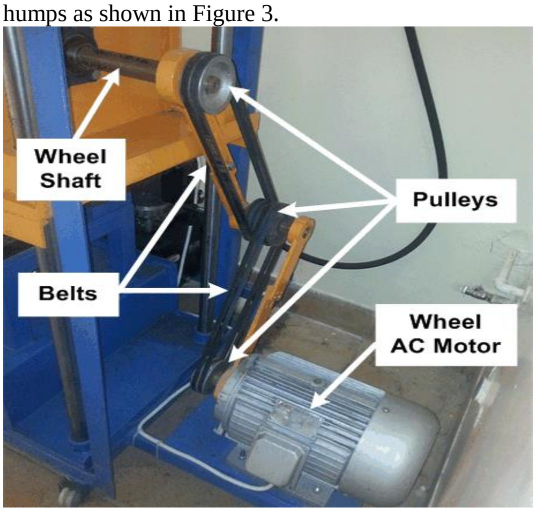


Figure 3. The crank shaft mechanism assisted with pulleys and belts to rotate the wheel while moving up and down.

In the proposed suspension test rig, the bumps and humps are emulated via an electrical rotary servo motor that is mounted at the bottom of the test rig as shown in Figure 4. The servo motor is coupled to a screw with a diameter of 10cm and 0.5cm pitch distance (i.e., one rotation provides a 5mm linear displacement per one revolution) to provide a precise linear motion. In fact, this motor excites the suspension system through the wheel by creating different shapes of bums and humps. Few examples are shown in Figure 5. The motor provides an instantaneous push (i.e., pulse) to the wheel while rotating to emulate the bump effect on the wheel (i.e., the vehicle suspension system). The motor was chosen to be servo so that it can be programmed to give a signal of constant amplitude, ramp, sinusoidal wave, or polynomial to emulate different kinds of bump actions. Servo systems are well known to provide precision in positioning and speed regulation.

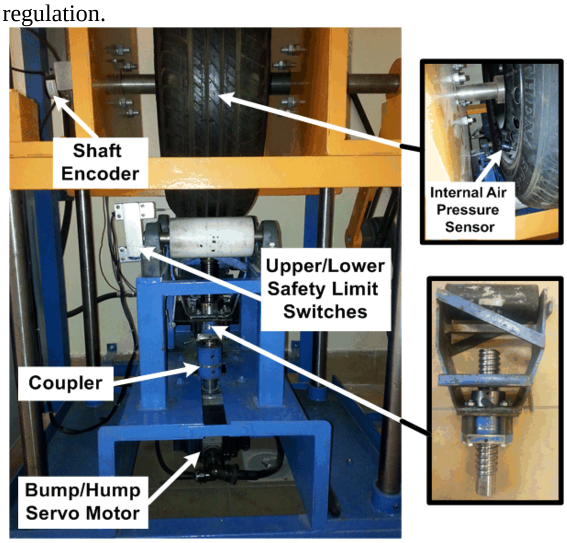


Figure 4. The motor-screw mechanism required to excite the suspension system.

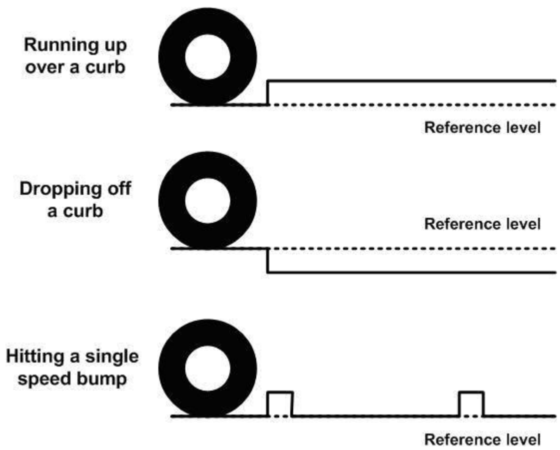


Figure 5. Examples of few bump types to excite the suspension system.

B. Actuators and Drive System

There are three actuators in the proposed test rig; two electrical and one hydraulic. One of the electrical actuators is used to rotate the wheel via the pulleys mounted in the crank shaft mechanism as shown in Figure 3. A 1.5kW three-phase induction motor is used with a rated speed of 1370RPM, rated phase voltage of 230V, and rated current of 9.64A. This AC motor was chosen to emulate the vehicle running at a maximum speed of 162km/h. An inverter is utilized in the drive system to allow changing the speed of the vehicle as desired. The second electrical motor is used to emulate the bumps and humps via a screw coupled to its shaft. A 2kW AC servo motor is used with a rated speed of 3000RPM and a rated current of 10A (e.g., LS Mecapion APM-S-C-20-A-E). The motor was chosen to handle the weight of the proposed quarter car (i.e., 300kg), suspension components, wheel, plates, and any other forces such as friction. One of the advantages of using a servo system is that it can produce a certain number of rotations to achieve a certain vertical displacement.

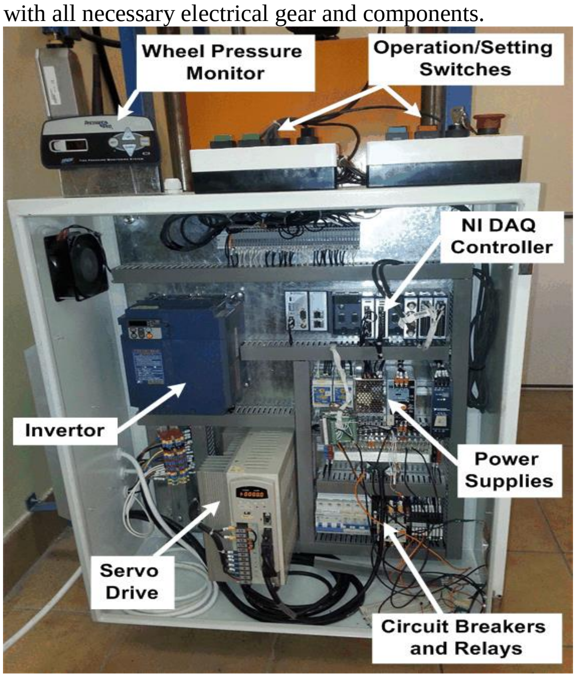
The hydraulic actuator is mainly used as an active suspension to handle the quarter car weight. In fact, either the passive suspension (i.e., spring and damper) or the active suspension (i.e., hydraulic actuator) can be used in the suspension test rig. Switching between both of them has to be done manually. More details about the hydraulic system utilized in the test rig can be found in subsection 3.E.

C. *Transducers*

Various sensors are distributed in different places in the proposed test rig. Two linear encoders (e.g., Lika SME51-L-2-10-R-2-B) and two accelerometers (e.g., PCB Piezotronics 603C01) are mounted on each moving plate to measure the linear position, speed, and acceleration. A shaft encoder (e.g., LS Mecapion S48-8-1024VL) is also mounted on the wheel shaft to measure the angular speed, hence, the vehicle speed. Two safety limit switches are mounted to prevent the bump or hump from exceeding the maximum displacement of 10 cm. A pressure sensor is mounted on the wheel, as shown in Figure 3, to provide real-time readings of the internal air of the wheel through a front monitor, as shown in Figure 6. Other sensors are used as part of the active suspension system (i.e., hydraulic unit) as presented in subsection 3.E. Note that an internal shaft encoder is embedded in the servo motor unit to provide measurements of position and speed. The torque of servo motor is measured internally by measuring active currents.

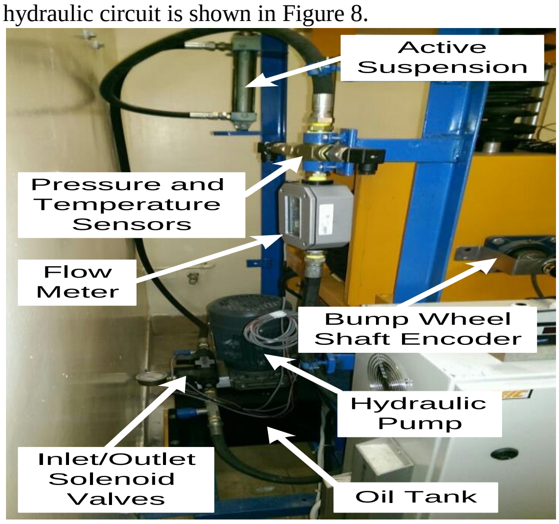
D. Main Controller

National Instruments (NI) Data Acquisition (DAQ) System (i.e., NI cRio-9074 integrated 400MHz real-time controller and 2M gate FPGA) is used as the main controller for the proposed suspension test rig. Using the LabVIEW software tool offers a great flexibility in programming as well as real-time implementation needed for any educational, training, and research purposes. Different control and measurement NI cards are used to provide variety of signals. In addition, the used NI cards are chosen to be compatible with any other electrical device used in the system, such as the drive units. The main advantage of using such interfacing system is the flexibility of changing I/O cards to suit any electrical components replaced or added to the test rig system. Figure 6 shows the control panel for the proposed test rig with all necessary electrical gear and components.



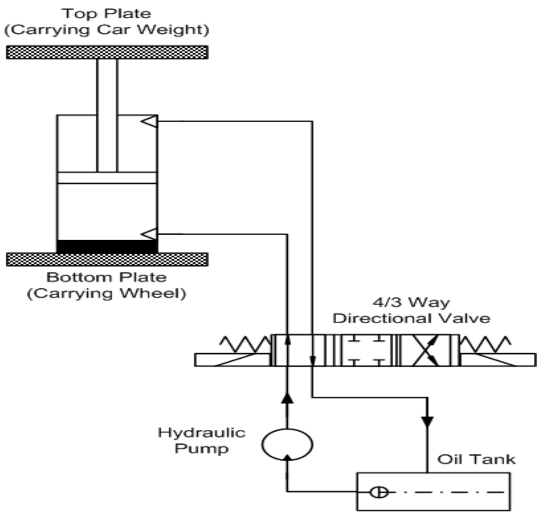
E. Hydraulic Unit

The active suspension configuration in the test rig was chosen to be a hydraulic system. Most small- and mid-sized vehicles with active suspension use hydraulic components in comparison with the pneumatic system that can be found in heavy duty vehicles such as big-size trucks. The pressure of the hydraulic unit is manually adjusted and features an oil tank with its pressure relief valve, 5hp-1500RPM hydraulic pump, a 4/3 way directional hydraulic double valve with mid way closed, and two inlets/outlets hydraulic cylinder with a piston rod of 50mm diameter, 150mm stroke, and working pressure of 150bar as shown in Figure 7. Various sensors are utilized such a flow meter (e.g., LakeMonitors LCM-505), pressure transducer (e.g., tecsis P3297), and temperature transducer (e.g., tecsis TEP11). Current-to-voltage convertors are used as well (e.g., Selet 1BS/OW) since some of the mounted sensors produce current signals. The hydraulic circuit is shown in Figure 8.



4. Conclusion and Future Work

A laboratory test rig is introduced to study the effect of road terrains on automotive suspension systems and to be used as an educational, training, and research tool. By using the proposed automotive test rig, various modeling and control techniques can be taught, designed, implemented, and tested experimentally. Eventually, the work introduced in this paper is the design, implementation, and integration of mechanical and electrical components to construct a test rig of an automotive suspension system that can be used for different purposes. In the future experimental performance testing is intended to be conducted to explore and investigate various identification and control strategies.



Acknowledgement

The present work is supported and funded by Hashemite University, Jordan, under grant no HU/12/12/2010.

References

[1] S. Qamar, T. Khan, and L. Khan, "Adaptive neuro-fuzzy sliding mode control based strategy for active suspension control". International Conference on Frontiers of Information Technology, Islamabad, Pakistan, 2010, pp. 107.115.

[2] G. Priyandoko, G., Mailah, M., and Jamaluddin, H., "Vehicle active suspension system using skyhook adaptive neuro active force control". Mechanical Systems and Signal Processing, Vol. 23 (2009) No. 3, 855–868.

[3] M. Jonasson, and F. Roos, "Design and evaluation of an active electromechanical wheel suspension system". Mechatronics, Vol. 18 (2008) No. 4, 218–230.

[4] D. Fischer, and R. Isermann, "Mechatronic semi-active and active vehicle suspensions". Control Engineering Practice, Vol. 12 (2004) No. 11, 1353–1367.

[5] X. Liu, and J. Wagner, "Design of a vibration isolation actuator for automotive seating systems – Part II: Controller design and actuator performance". International Journal of Vehicle Design, Vol. 29 (2002) No. 4, 357–375.

[6] F. Kou, and Z. Fang, "An experimental investigation into the design of vehicle fuzzy active suspension". International Conference on Automation and Logistics, Jinan, China, 2007, pp. 959–963.

[7] Y. Zhang, K. Huang, F. Yu, Y. Gu, and D. Li, "Experimental verification of energy-regenerative feasibility for an automotive electrical suspension system". IEEE International Conference on Vehicular Electronics and Safety, Beijing, China, 2007, pp. 1.5.

[8] Y.S. Pathare, and S. R. Nimbalkar, "Design and development of quarter car suspension test rig model and its simulation". International Journal of Engineering Science and Advanced Technology, Vol. 3 (2014) No. 3, 157-170.

[9] V. Sankaranarayanan, M. Emekli, B. Guvenc, L. Guvenc, E. Ozturk, E. Ersolmaz, I. Eyol, and M. Sinal, "Semiactive suspension control of a light commercial vehicle". IEEE/ASME Transactions on Mechatronics, Vol. 13 (2008) No. 5, 598–604.

[10] C. Poussot-Vassal, O. Sename, L. Dugard, P. Gaspar, Z. Szabo, and J. Bokor, "A new semi-active suspension control strategy through LPV technique". Control Engineering Practice, Vol. 16 (2008) No. 12, 1519–1534.

[11] M. Fateh, and A. Alavi, "Impedance control of an active suspension system". Mechatronics, Vol. 19 (2009) No. 1, 134–140.

[12] K. Rajagopal, and L. Ponnusamy, "Hybrid DEBBO algorithm for tuning the parameters of PID controller applied to vehicle active suspension system". Jordan Journal of Mechanical and Industrial Engineering, vol. 9, no. 2, pp. 85-101, 2015.

[13] C. Lauwerys, J. Swevers, and P. Sas, "Robust linear control of an active suspension on a quarter car test-rig". Control Engineering Practice, Vol. 13 (2005) No. 5, 577–586.

[14] N. Yagiz, and Y. Hacioglu, "Backstepping control of a vehicle with active suspensions". Control Engineering Practice, Vol. 16 (2008) No. 12, 1457–1467.

[15] S. Choi, and S. Han, "H∞ control of electrorheological suspension system subjected to parameter uncertainties". Mechatronics, Vol. 13 (2003) No. 7, 639–657.

[16] N. Yagiz, Y. Hacioglu, and Y. Taskin, "Fuzzy sliding-mode control of active suspensions". IEEE Transactions on Industrial Electronics, Vol. 55 (2008) No. 11, 3883–3890.

[17] S. Yildirim, "Vibration control of suspension systems using a proposed neural network". Journal of Sound and Vibration, Vol. 277 (2004) No. 4–5, 1059–1069.

[18] T. Gordon, "Non-linear optimal control of a semi-active vehicle suspension system". Chaos, Solitons, and Fractals, Vol. 5 (1995) No. 9, 1603–1617.

[19] J. J. Rath, M. Defoort, H. R. Karimi, and K. C. Veluvolu, "Output Feedback Active Suspension Control With Higher Order Terminal Sliding Mode". IEEE Transactions on Industrial Electronics, Vol. 64 (2017) No. 2, 1392–1403.

[20] G. Koch, E. Pellegrini, S. Spirk, and B. Lohmann, "Design and modeling of a quarter-vehicle test rig for active suspension control". Technical Reports on Automatic Control, Vol. TRAC-5 (2010), 1-28.

[21] D. H. Alcantara, R. Morales-Menendez, and L. Amezquita-Brooks, "Fault diagnosis for an automotive suspension using particle filters". European Control Conference (ECC), Aalborg, Denmark, 2016, pp. 1898–1903.

[22] D. H. Alcantara, R. Morales-Menendez, and R. A. Ramírez Mendoza, "Teaching semi-active suspension control using an experimental platform". American Control Conference (ACC), Boston, MA, USA, 2016, pp. 7334–7339