A Hybrid Optimization Method To Improve Driver's Comfort

Kornel Warwas
Department of Computer Science and Engineering
University of Bielsko-Biała
Bielsko-Biała, Poland
kwarwas@ath.bielsko.pl

Szymon Tengler
Department of Mechanics
University of Bielsko-Biała
Bielsko-Biała, Poland
stengler@ath.bielsko.pl

Abstract—**In this paper a hybrid optimization method consisting in conjunction an evolutionary algorithm and a classical optimization method has been presented. This hybrid method has been used to select the parameters of a driver's seat of a special vehicle, which contributes directly to increase in driving comfort. A brief description of a vehicle mathematical model was formulated by using joint coordinates and homogenous transformations. Numerical simulations of optimization and dynamics have been performed over obstacles in a form of a speed bump. A subject of the investigations was to select such damping parameters to minimize amplitudes of driver's seat vibrations.**

Keywords—hybrid optimization method; vehicle dynamics; driving comfort; active damping; computer simulations

I. Introduction

Driving comfort in the vehicles is a subject of considerations of many papers [1, 2, 3, 4]. A comfort improvement can have a significant influence on both effective time of vehicle use and a level of operator tiredness. It is particularly important in the case of articulated and special vehicles in which an operator spends daily on average from a few to over a dozen hours [2]. A lot of research deals with human-seat interaction [5, 6, 7]. In these works authors focus on accurate modelling of human body with seat contact. As it is shown in [8, 9, 10] the comfort improvement of a driver and passengers is frequently identified with modifications of vehicle sub-assemblies. In this case researchers do not include the human body interaction but they are focused on changes and improvements in the vehicle elements such as suspension, and those systems are commonly called an active or semi-active suspension [1, 9, 10]. Seats, and in particular a driver's seat, are a next sub-assembly which has a direct influence on the driving comfort [11]. In this case a reduction of the vibrations occurring while driving over the uneven road surfaces can turn out to be an important factor affecting the driving comfort improvement [12]. An influence of uneven road surfaces on the driver's seat behavior is presented as an example in works [13]. The authors used a magneto-rheological shock absorber to improve driving comfort. Regulators and actuators which must be calibrated properly, are usually used to select optimum parameters of the sub-assemblies [1, 9, 10]. The selection of the appropriate parameters of the vehicle sub-assemblies can be also made by solving an optimization task. In order to solve an issue how to select proper values of the driver's seat parameters, different methods of dynamic optimization were used in works [14]. Analyses were made related to a selection of the functional used in the optimization task. Often for solving optimization problem the classical methods or evolutionary algorithms such as a genetic algorithm are used [14, 15, 16]. For example in work [17] the genetic algorithm for comfort improvement through active damping has been used. In paper [18] a novel control scheme for the active suspension in a 4-DOFs half-car model using was presented. The genetic algorithm was used to search for damping ratio and spring constant to achieve an optimum trade off among ride comfort. Computer simulations are performed using MATLAB software. Sometimes authors apply combination of several methods developing authorial algorithms. For example in papers [19, 20] authors increased efficiency of fuzzy PID controller by using the genetic algorithm. However in the cited papers authors analyze reduced vehicle model complexity or only the vehicle subassembly.

In this article the investigations concerned an improvement of comfort of driving by a special vehicle. The vehicle has been modelled as a spatial multibody system. Also authors' models of road surface and own algorithms to improve driver comfort were used. A computer simulations of a vehicle motion were performed over an obstacle in a form of a speed bump.

II. Mathematical Model

An object of testing is a rescue fire-fighting vehicle being an example of a special vehicle with a high gravity center. In the analyzed vehicle there were ten sub-assemblies identified such as: a frame, a cabin, a driver's seat, a body, an engine, a front and rear axle and wheels (fig. 1).

Joint coordinates and homogenous transformations were used to determine a position and orientation of these bodies in the three-dimensional space [14, 21]. At such a way of modeling motion of each body (except for the base body), is determined in relation to a preceding body, and this motion is described by the generalized coordinates assumed appropriately.

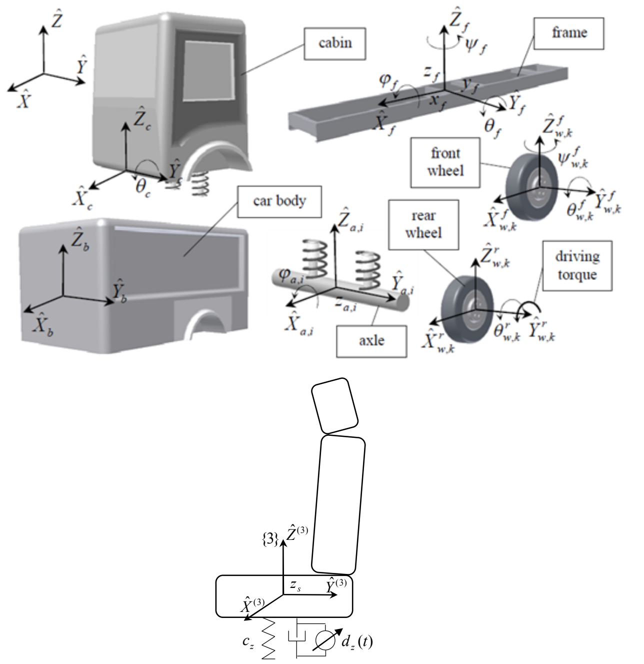

Fig. 1. Subassemblies of the vehicle

For each body of the vehicle model the vector of generalized coordinates has been determined as follows: $\mathbf{q}_f = [x_f \quad y_f \quad z_f \quad \psi_f \quad \theta_f \quad \varphi_f]^T$ - frame, $\mathbf{q}_c = [\theta_c]^T$ - cabin; $\mathbf{q}_s = [z_s]$ - driver's seat; $\mathbf{q}_b = \{\emptyset\}$ - car body fixed to frame; $\mathbf{q}_{a,i} = [z_{a,i}, \varphi_{a,i}]^T$ - axles ($i = 1$ front, $i = 2$ rear); $\mathbf{q}^f_{w,k} = [\psi^f_{w,k}, \theta^f_{w,k}]^T$, $\mathbf{q}^r_{w,k} = [\theta^r_{w,k}]^T$ - wheels (f - front, r - rear; $k = 1$ right, $k = 2$ left). The vector of the generalized coordinates of vehicle has the following form:

$$\mathbf{q} = \begin{bmatrix} \mathbf{q}_f{}^T & \mathbf{q}_c{}^T & \mathbf{q}_s{}^T & \mathbf{q}_b{}^T & \mathbf{q}_{a,1}{}^T \\ \mathbf{q}_{a,2}{}^T & \mathbf{q}^f_{w,1}{}^T & \mathbf{q}^f_{w,2}{}^T & \mathbf{q}^r_{w,1}{}^T & \mathbf{q}^r_{w,2}{}^T \end{bmatrix}^T \tag{1}$$

The multibody system can be presented as a tree structure containing the open kinematic chains (fig. 2). Nodes of this tree are bodies modeling particular sub-assemblies.

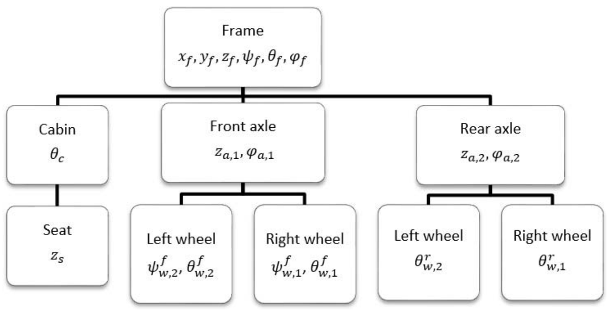

Fig. 2. Models of the sub-assemblies forming the tree structure of the vehicle.

Equations of vehicle motion have been formulated using Lagrange equations of the second kind [21]:

$$\frac{d}{dt}\frac{\partial E}{\partial \dot{q}_k} - \frac{\partial E}{\partial q_k} + \frac{\partial V}{\partial q_k} + \frac{\partial V_D}{\partial \dot{q}_k} = Q_k \tag{2}$$

where: $E = \sum_{p=1}^{N} E^{(p)}$ - total kinetic energy of the vehicle,

$E^{(p)}$ - kinetic energy of the p-th body,

$V = \sum_{p=1}^{N} V^{(p)}$ - total potential energy of the vehicle,

$V^{(p)}$ - potential energy of the p-th body,

$V_D = \sum_{p=1}^{N} V_D^{(p)}$ - total energy dissipation function of the vehicle,

$V_D^{(p)}$ - energy dissipation function of the p-th body,

$\dot{\mathbf{q}} = \frac{d\mathbf{q}}{dt} = (q_k)_{k=1,\ldots,n}$ - vector of generalized velocities,

$\mathbf{Q} = (Q_k)_{k=1,\ldots,n}$ - vector of generalized forces,

N - number of bodies of the vehicle,

n - number of generalized coordinates of the vehicle,

$k = 1, \ldots, n$.

In works [22, 23] there is a detailed description of mathematical modelling which results in a calculation model and dynamic equations of motion in a matrix form written as:

$$\begin{cases} \mathbf{A}\ddot{\mathbf{q}} - \mathbf{\Phi}_q \mathbf{r} = \mathbf{f} \\ \mathbf{\Phi}_q{}^T \ddot{\mathbf{q}} = \mathbf{w} \end{cases} \tag{3}$$

where: $\mathbf{A}$ - mass matrix,

$\ddot{\mathbf{q}}$ - vector of generalized acceleration of the vehicle,

$\mathbf{\Phi}_q$ - constraints matrix,

$\mathbf{f}$ - vector of external, Coriolis and centrifugal forces,

$\mathbf{r}$ - vector of unknown constraint reactions corresponding to torques acting on stub axles connected with the wheels,

$\mathbf{w}$ - vector of right sides of constraint equations.

The details of the procedure which leads to form equation (3) with a description of elements in the matrix $\mathbf{A}$ and vector $\mathbf{f}$ are presented in [22].

III. Optimisation Problem

The main aim of optimization is to select certain vehicle parameters to provide the best possible driving comfort. In the issue in question the decisive variables determine the damping coefficients of the driver's seat sub-assembly in the discrete time moments:

$$\mathbf{d} = \begin{bmatrix} d_1 & \dots & d_i & \dots & d_{n_d} \end{bmatrix}^T \tag{4}$$

where: d_i - value of driver's seat damping coefficient,

n_d - number of the discrete timestamps.

Spline functions of the first degree were used to obtain a continuous function of the decisive variables. Additionally, inequality constraints determining the minimum and maximum values of the damping coefficients were considered:

$$d_{\min} \le d_i \le d_{\max} \tag{5}$$

These constraints were taken into account in the optimization task by the external penalty function [24, 25], of which value was added to the objective function minimized:

$$\xi_i(\mathbf{d}) = \begin{cases} 0 & \text{for} \quad g_i(\mathbf{d}) \le 0 \\ C_{1,i} \exp\left(C_{2,i} g_i(\mathbf{d})\right) & \text{for} \quad g_i(\mathbf{d}) > 0 \end{cases} \tag{6}$$

where: $g_i(\mathbf{d})$ - the inequality constraint,

$C_{1,i}$, $C_{2,i}$ - weights selected empirically.

In the optimization process there were separate analyses made in which the following functionals were minimized:

$$\Omega(\mathbf{d}, \ddot{\mathbf{q}}) = \frac{C}{t_e} \sqrt{\int_0^{t_e} \left(\ddot{z}^{(3)}\right)^4 dt} + \sum_{i=1}^{n_g} \xi_i(\mathbf{d}) \to \min \tag{7}$$

where: t_e - simulation duration,

n_g - a number of the inequality constraints,

C - weight selected empirically.

The problem was solved by the Variable Metric Method and the Genetic Algorithm. The domain of the evolution methods is to find the global extreme in the state space. The classical methods are characterized by determining the extremum in a more precise way, however, they are prone to local extrema and strongly depend on a starting point. Therefore, a hybrid method consisting in combining the evolution method with classical one, was used in the work (fig. 3).

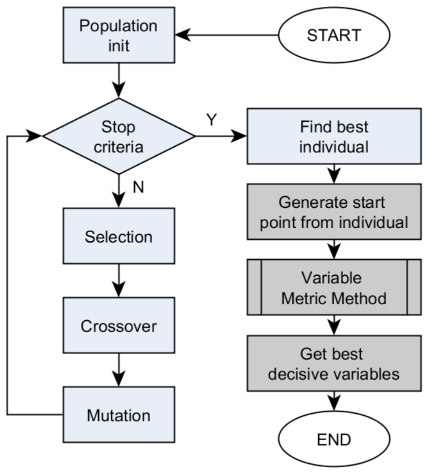

Fig. 3. Flowchart of hybrid optimization method.

Firstly, calculations by the Genetic Algorithms are made. The decisive variable values determined in such a way are taken as the starting point in the Variable Metric Method. Such a procedure enables to improve driver's comfort more significantly than in event of applying these two methods separately. The real-value representation of genes in the chromosome was used in the genetic algorithm. The following genetic operators were used [26]:

- selection - an operator selecting chromosomes to reproduce, according to a principle that chromosomes of higher values of the objective function are selected more frequently,

- crossover - an operator selecting two chromosomes at random, and then changing a sequence of their genes. The arithmetic crossover [23, 25, 26] in which a new chromosome is a linear combination of two vectors, was used:

$$\begin{aligned} \mathbf{d}_i^{(*)} &= a\mathbf{d}_i + (1-a)\mathbf{d}_j \\ \mathbf{d}_j^{(*)} &= (1-a)\mathbf{d}_i + a\mathbf{d}_j \end{aligned} \tag{8}$$

where: $\mathbf{d}_i$, $\mathbf{d}_j$ - i-th i j-th chromosome (ancestor),

$\mathbf{d}_i^{(*)}$, $\mathbf{d}_j^{(*)}$ - i-th i j-th a descendent of chromosomes $\mathbf{d}_i$ i $\mathbf{d}_j$ (descendant),

$a \in [0,1]$ - random number,

- mutation – an operator changing at random values of the genes in the chromosome. In the paper uniform mutation [23, 25, 26] was used. If gene d_i of specific chromosome $\mathbf{d} = \begin{bmatrix} d_1 & \dots & d_i & \dots & d_{n_d} \end{bmatrix}^T$ was selected for mutation, the result is:

$$\mathbf{d}^{(*)} = \begin{bmatrix} d_1 & \dots & d_i^{(*)} & \dots & d_{n_d} \end{bmatrix}^T \tag{9}$$

where: $d_i^{(*)} = \begin{cases} d_i + \Delta(d_{\max} - d_i) & \text{for} \quad b = 0 \\ d_i - \Delta(d_i - d_{\min}) & \text{for} \quad b = 1 \end{cases}$,

$b \in \{0,1\}$ - random number,

$\Delta(d) \in [0, d]$ - random number,

n_d - number of gens in chromosome.

The results of the numerical simulations performed for the selected road case and a comparison of the results obtained while conducting the numerical simulations for an objective function and the decisive variables are presented further in the article.

IV. Results of Numerical Calculation

A case in which a vehicle driving with a constant velocity drives over an obstacle in a form of speed bumps of 0.06 m height is presented in fig. 4.

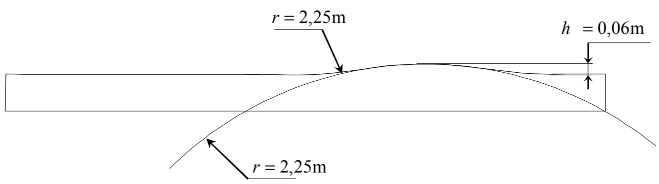

Fig. 4. The profile of the analyzed speed bump.

An object of the investigation was to determine the optimal coefficients providing a reduction of the driver's seat vibrations while performing the maneuver. In the numerical simulations it has been assumed that the maneuver lasted 3 sec. in which the vehicle drove over the obstacle (the speed bump) with the front and rear wheels. Two variants of constant velocity equal to 10 km/h and 15km/h provided by controlling the driving torque moments using PID regulator [22], were assumed. The physical parameters of the vehicle necessary to perform the simulation were taken from work [22]. The driver model was accounted in the calculations and dynamic equations of motion as additional mass of 80 kg weight joined with the driver's seat. The constant step Runge-Kutta method of 4-th order was used to integrate equations of motion in each optimization step. The minimal and maximal values of the damping coefficients being inequality constraints were taken $d_{z,\min} = 10$ Ns/m and $d_{z,\max} = 4000$ Ns/m, respectively. The fig. 5 and fig. 6 present the results of courses of the values of the objective function for two velocity variants. Those values were marked as: Bo - without optimization, VMM - using Variable Metrics Method, $GA_{10\text{-}50}$ - using the Genetic Algorithm with a variable number of chromosomes in population (from 10 to 50). The results obtained from the calculations indicate that the evolution method shows a slight advantage over the classical method.

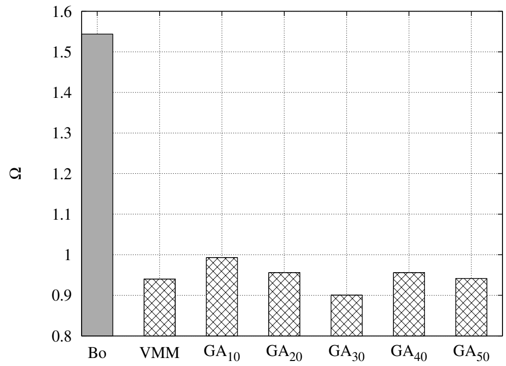

Fig. 5. Values of the objective function for velocity 10 km/h.

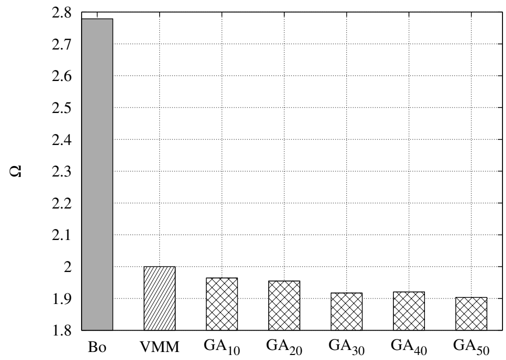

Fig. 6. Values of the objective function for velocity 15 km/h.

It is particularly apparent for 15 km/h speed and a greater number of beings in the population. In the further part of the paper calculations were made by use of the hybrid method according to the algorithm presented in fig. 3. In the first stage the best chromosome was selected (the decisive variable vector). For 10 km/h speed it was a being from population GA_{30}, and for 15 km/h speed GA_{50} was selected. Then, the selected values of the decisive variables were used as the starting point for the Variable Metrics Method. After performing optimization calculations by the VMM method the results are presented in fig. 7 and 8.

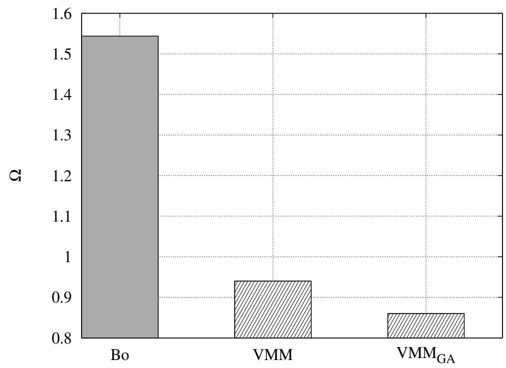

Fig. 7. Values of the objective function for velocity 10 km/h.

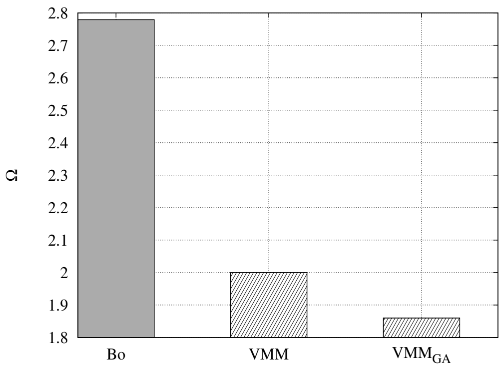

Fig. 8. Values of the objective function for velocity 15 km/h.

As it can be seen much better results were obtained while using the hybrid method (a lower value of the objective function) than while applying the GA and VMM methods separately. An application of the hybrid method has a slight impact on lengthening time of the optimization calculations. However, this increment is low because the VMM method for the starting point in the neighborhood of the global extreme (obtained from GA) performs only a few iterations.

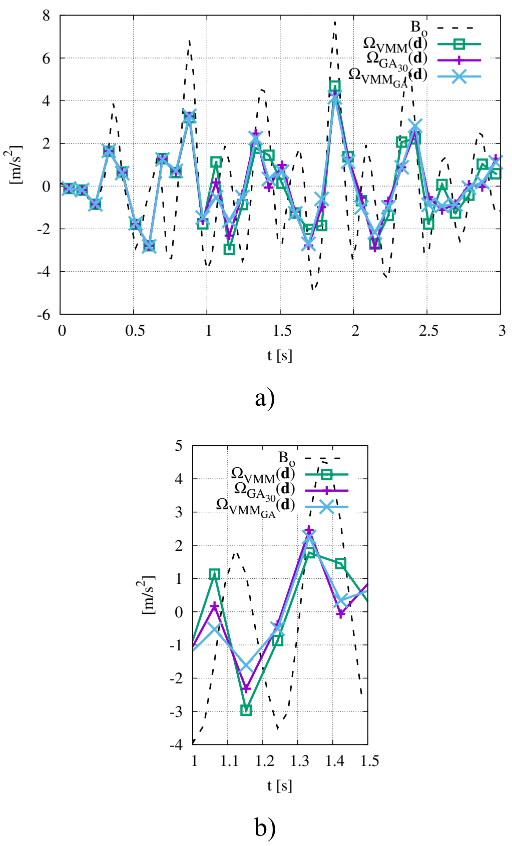

Fig. 9. Courses of the driver's seat acceleration of the damping optimization for velocity 10 km/h.

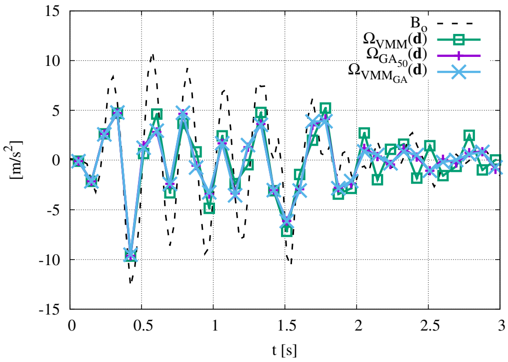

Fig. 10. Courses of the driver seat acceleration of the damping optimization for velocity 15 km/h.

In the further part of the study an analysis of special vehicle dynamics, including the results from different optimization methods, was made. The results of those analyses are presented in the form of courses of driver's seat accelerations. (fig. 9 and 10). It can be noticed that the acceleration amplitudes are significantly lower when all presented optimization methods are used. The lowest values were obtained for the hybrid method what is particularly noticeable in fig. 9b. Courses of the decisive variables obtained in the optimization process by the VMM and hybrid method are presented below.

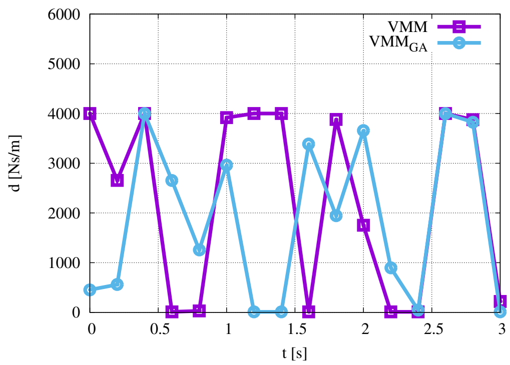

Fig. 11. Courses of the damping decisive variables the driver seat obtained in the optimization process for velocity 10 km/h.

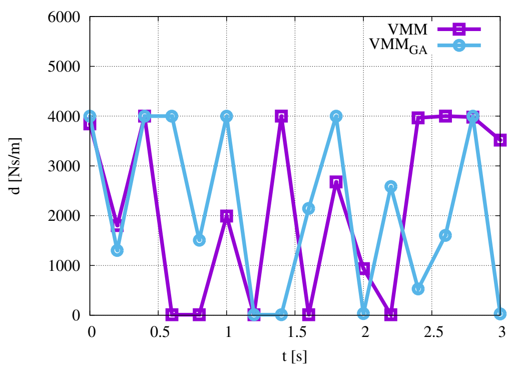

Fig. 12. Courses of the damping decisive variables the driver seat obtained in the optimization process for velocity 15 km/h.

A lower value of the objective function obtained from optimization by the hybrid method influences courses of the decisive variables (fig. 11 and 12).

V. CONCLUSIONS

The article presents a solution of selecting the parameters of active damping of the driver's seat using the dynamic optimization, by integrating an equation of motion of the vehicle in each iteration. The hybrid method, consisting in combining the results obtained from the evolution method with the VMM classical method was used in the calculations. It facilitated to find the global minimum of the objective function by using features of these optimization methods. The genetic algorithm served for determining the approximated extremum of the analyzed functional, whereas a few further iterations made by the classical method (VMM) allowed obtaining the accurate extremum. The results indicate that use of the hybrid method enabled to obtain better results than use of the presented GA and VMM methods separately. In case of using only the VMM method the driver's comfort was increased by at least 30%. Whereas by using the hybrid method the driver's comfort was increased by about additional 5%. According to the authors any improvement is important in this type of issues due to their complexity and has a direct influence on driver's feeling of comfort. The calculations were made for the selected road maneuver with the obstacle in a form of the speed bump. The numerical analyses also indicate that with an increase in the acceleration caused by road unevenness, the dynamical optimization conducted properly can improve significantly driving comfort of a driver. It should be emphasized that the performed studies deal with one road maneuver and a shape of the speed bump. However, authors conducted a number of other simulations taking into account the different types of road unevenness and speed. The presented procedure algorithm is universal and can be applied in other vehicle sub-assemblies and multibody systems. In this article the presented algorithm improves significantly driving comfort of a special vehicle driver, although due to long time of calculations it can be used only to verify the existing controllers. The presented algorithm can be also used in an artificial neuron network for an intelligent damping control in order to prepare an appropriate training set. After training the neuron network can be used in the controller in a real time.

REFERENCES

[1] E. Guglielmino, T. Sireteanu, C. Stammers, G. Ghita, M. Giuclea, "Semi-active Suspension Control", Improved Vehicle Ride and Road Friendliness, Springer-Verlag London, 2008.

[2] G. Sammonds, M. Fray, N. Mansfield, "Overall car seat discomfort onset during long duration driving trials", Advances in Physical Ergonomics and Human Factors Part II, AHFE Conference Books, 2014, pp. 25-35.

[3] S. Yang, L. Chen, S. Li, Dynamics of Vehicle-Road Coupled System, Springer-Verlag Berlin, 2015.

[4] K. Jamroziak, M. Kosobudzki, J. Ptak, "Assessment of the comfort of passenger transport in special objective vehicles", Ekspolatacja i Niezawodność – Maintenance and Reliability, 15 (1), 2013, pp. 25-30.

[5] K. Chimote, M. Gupta, "Integrated Approach Of Ergonomics And Fem Into Truck Drivers Seat Comfort", 1st International and 16th National Conference on Machines and Mechanisms, IIT Roorkee, 2013, pp. 183-188.

[6] I. Mircheski, T. Kandikjan, S. Sidorenko, "Comfort analysis of vehicle driver's seat through simulation of the sitting process", Tehnički vjesnik 21, 2014, pp. 291-298.

[7] P. Gunther, J. Pendlebury, J. Miller, "The contribution of seat components to seat hardness and the interface between human occupant and a driver seat", International Journal of Human Factors Modelling and Simulation, 2012, pp. 378-397.

[8] P. Holen, B. Thorvald, "Possibilities and limitations with distributed damping in heavy vehicles",Vehicle System Dynamics Supplement 41, 2004, pp. 172-181.

[9] K. Rao, S. Kumar, "Modeling and Simulation of Quarter Car Semi Active Suspension System Using LQR Controller", Proceedings of the 3rd International Conference on Frontiers of Intelligent Computing: Theory and Applications (FICTA), Springer-Verlag, 2015, Vol. 1, pp. 441-448.

[10] S. Savaresi, C. Poussot-Vassal, C. Spelta, O. Sename, L. Dugard, Semi-Active Suspension Control Design for Vehicles, Elsevier Ltd., 2010.

[11] X. Zhu, S. Zhu, "A Theoretical Model for Calculating Vibration Characteristics of A Kind of Driver Seat with Air Spring and MR Damper", Applied Mechanics and Materials, Vol. 141, 2012, pp. 8-14.

[12] M. Rezaee, A. Osguei, H. Arghand, "An investigation on the ride comfort of a vehicle subjected to the random road excitation", International Journal of Vehicle Safety 6(3), 2013, pp. 235-253.

[13] E. Attia, F. Ayman, H. El Gamal, B. El Souhily, "Effect of Irregular Road on Dynamic Response of Car Seat Suspended by a Magneto-Rheological (MR) Damper", International Journal of Applied Science and Technology, 2014, No. 5, Vol. 4, pp. 39-54.

[14] S. Tengler, K. Warwas, Active damping of special vehicle seat, Modelling in Engineering, No. 59, 2016, pp. 86-91.

[15] C. Song, Y. Zhao, L. Wang, "Design of active suspension based on genetic algorithm," Conference on Industrial Electronics and Applications, 2008, pp. 162-167.

[16] W. Abbas, O. Abouelatta, M. El-Azab, A. Megahed, "Genetic algorithms for the optimal vehicle's driver-seat suspension design", Ain Shams Journal of Engineering Physics and Mathematics, Vol. 2, 2009, pp. 17-29.

[17] R. Gupta, V. Sonawane, D. Sudhakar, "Optimization of vehicle suspension system using genetic algorithm", Vol. 6, 2015, pp. 47-55.

[18] M. Hada, A. Menon, S. Bhave, "Optimisation of an Active Suspension Force Controller using Genetic Algorithm for Random Input", Defence Science Journal, Vol. 57, No. 5, 2007, pp. 691-706.

[19] S. Mouleeswaran, "Genetic algorithm-based proportional derivative controller for the development of active suspension system", Information Technology and Control, Vol. 36, No.1, 2007, pp. 58-67.

[20] Q. Guo, D. Hua, L. Kong, "Hybrid Control Strategy of Vehicle Semi-active Suspension Based on the Genetic Algorithm Optimization", Metallurgical and Mining Industry, 2015, pp. 70-78.

[21] I. Adamiec-Wójcik, J. Awrejcewicz, W. Grzegożek, S. Wojciech., "Dynamics of articulated vehicles by means of multibody methods", Dynamical systems : mathematical and numerical approaches, 2015, pp. 11-20.

[22] S. Tengler, Analiza dynamiki samochodów specjalnych o wysoko położonym środku ciężkości, PhD Thesis, Faculty of Mechanical Engineering and Computer Science, University of Bielsko-Biala, 2012.

[23] K. Warwas, Analiza i sterowanie ruchem pojazdów wieloczłonowych z uwzględnieniem podatności elementów, PhD Thesis, Faculty of Mechanical Engineering and Computer Science, University of Bielsko-Biala, 2009.

[24] W. Press, Teukolsky W., Vetterling S., Flannery W. B., Numerical Recipes 3rd Edition: The Art of Scientific Computing, Cambridge University Press, Cambridge, 2007.

[25] R. Paulavičius, J. Žilinskas, Simplicial Global Optimization, Springer-Verlag New York, 2014.

[26] Z. Michalewicz, Genetic Algorithms + Data Structures = Evolution Programs, Springer Science & Business Media, 2013.