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SIAR – SOCIETATEA INGINERILOR DE AUTOMOBILE DIN ROMÂNIA
30 ANI DE ACTIVITATE

CUNOAȘTERE ȘI DEZVOLTARE, PRIN COOPERARE!

- Influența semnalului de excitație asupra comportamentului dinamic al unui amortizor magnetoreologic
- Model de predicție a distanței de frânare a vehiculelor folosind teste de frânare
- Identificarea factorilor de influențare a proiectării și dezvoltării autoturismelor folosind platforme modulare de producție
- Simularea și compararea cantității de emisii poluante după optimizarea PID a funcționării motorului unui autoturism AUDI A6
- Analiza experimentală a proprietăților fizice ale combustibililor motoarelor Diesel

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FISITA INTERNATIONAL FEDERATION OF AUTOMOTIVE ENGINEERING SOCIETIES

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SISTEME DE PROPULSIE ALTERNATIVĂ A AUTOMOBILELOR

Autor (*Author*): **Cornel STAN**

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Lucrarea prezintă viitoarele sisteme de propulsie alternativă a autovehiculelor, pe baza celor mai recente rezultate din cercetare și dezvoltare în domeniu la nivel internațional, cu exemple de prototipuri și de automobile realizate de curând în producție de serie.
Vehicule cu propulsie electrică și baterii sau pile de combustibil, hibrizi și sisteme plug-in sunt tratate în fluxul cauzal și funcțional între energia folosită și lucrul mecanic dezvoltat la roată. În acest mod se pot determina atât consumul de energie, cât și emisiile de gaze în atmosferă pentru întregul ciclu de la asigurarea energiei respective, fabricarea vehiculului și a bateriilor, până la funcționare.
Surse alternative de energie, tehnici moderne de încărcare a bateriilor din automobilele electrice și prezentarea celor mai noi configurații realizate în producția de serie în lume constituie elementele noi față de ediția anterioară.
Actualizarea documentării și a analizei în vederea realizării acestei lucrări demonstrează o linie clară: viitorul automobilelor constă în diversificarea și adaptarea inteligentă a structurii și a sistemelor de propulsie electrică și termică, pe bază de module funcționale și nu unei soluții rigide, unitare, voită universală.

TERMODINAMICA PENTRU CONSTRUCȚIA DE MAȘINI ȘI AUTOVEHICULE

Autor (*Author*): **Cornel STAN**
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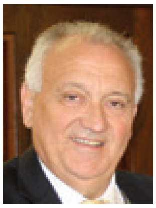
Termodinamica tehnică este coloana de bază a neutralității climatice, având ca domenii principale transformarea și transmiterea energiei sub formă de caldură și lucru mecanic în sistemele tehnice. Un element central al acestor procese este arderea combustibililor, cu un accent deosebit pe cei reciclabili.
Obiectivul principal al acestei lucrări este de a oferi studenților și inginerilor de dezvoltare și cercetare în domeniile construcțiilor de mașini și autovehicule atât rutine, cât și metode fenomenologice de calcul și dezvoltare de sisteme tehnice și procese cu potențial ridicat de protejare a mediului. Formulele prezentate sunt dezvoltate în totaliatea lor de la baza fizică până la forma finală, evitând folosirea de fragmente sau coeficienți fără explicație.
Fiecare capitol conține probleme și exerciții rezolvate, dar și exerciții a căror rezolvare se află la sfârșitul fiecărui capitol. Unul din capitole este dedicat simulării numerice tridimensionale a componetelor și proceselor în modulele mașinilor și autovehiculelor moderne.

Lucrările prezentate fac parte din fondul bibliografic al Centrului de documentare al SIAR.

AUTOMOBILELE VIITORULUI ŞI CREATORII LOR

FUTURE CARS AND CARMAKERS



Automobilele viitorului sunt percepute şi interpretate de masele largi, de mass-media şi de politicienii momentului ca mijloace de transport individual autopropulsate, autoghidate, comandabile de către oricine, oriunde şi oricând printr-un app pe smartphone şi care au doar două atribute: propulsie electrică şi conectivitate maximă. Complet ignorate rămân sistemele pentru asigurare a direcţiei, stabilităţii, rezistenţei, amortizării şocurilor şi vibraţiilor, sistemele de siguranţă activă şi pasivă, sistemele de climatizare, respectiv de încălzire, sistemele de iluminat, elementele de confort. Fiecare din aceste sisteme este însă definit prin complexitate, greutate, volum şi cost, iar toate împreună trebuie să fie integrate într-o caroserie cât mai uşoară, foarte rezistentă, dar şi suficient de încăpătoare pentru pasageri şi bagaje.

Este adevărat, pentru mobilitatea individuală în marile metropole ale lumii, în care în următorii 20-30 de ani vor trăi aproape două treimi din locuitorii planetei, asemenea vehicule unitare, reduse la funcţia de tabletă inodoră, incoloră, insipidă, purtătoare de tabletişti, poate constitui o soluţie pragmatică.

Dar mai rămâne şi restul lumii, şi restul activităţilor lumii: avem nevoie de tractoare, de combine, de camioane puternice pentru construcţii şi pentru transport, avem nevoie de maşini simple, dar încăpătoare pentru oameni nevoiaşi, avem nevoie de maşini de teren pentru transport şi lucru prin munţii şi pădurile lumii, pentru stepe şi deşerturi.

Autovehiculele viitorului vor fi create ca jocuri inteligente de LEGO – o explozie de diversitate, atât a caroseriilor, cât şi a sistemelor de propulsie.

În multe state europene a fost decisă de către actualii legiuitori interzicerea automobilelor cu motoare termice, începând din 2030-2035. Numai propulsie electrică? Şi tractoarele, şi camioanele, semănătoarele, avioanele?

Tocmai am citit într-un cunoscut jurnal automobilistic din Germania despre înfruntarea a două noi vehicule recent lansate de Mercedes (GLE Coupé), respectiv de Audi (Q8), fiecare costând cam 100.000 de euro. Ambele cu motoare Diesel biturbo sănătoase, cu şase cilindri, cu puteri de 200-210 kW! Cine nu înţelege care va fi viitorul automobilelor: marii producători, ziariştii, politicienii?

Mesajul meu pentru inginerii de automobile din România: pregătiţi-vă pentru diversitate, complexitate, modularizare şi interdisciplinaritate!

În construcţia automobilului au pătruns puternic informatica, electronica, electrotehnica, materialele şi tehnologiile neconvenţionale, tehnica medicală, psihologia, neurologia.

Atât specializarea, cât şi cunoştintele la interferenţa domeniilor au devenit condiţii de bază pentru creatorii moderni de automobile. Este imperativ ca aceşti creatori să facă atât cercetare fundamentală în domeniu, cât şi cercetare aplicată, în cadrul contractelor cu firme sau a celor finanţate prin programe europene sau naţionale. Trebuie studiată şi folosită literatura de specialitate internaţională la zi, nu este suficient să o cităm în studii, în articole sau în lucrări de doctorat, doar pentru că aduce puncte de tot felul – impact, citations, etcetera – folosibile, poate, în cariera văzută în plan administrativ. Ştiinţa, doar citită, tocită, dar neaplicată, nedezvoltată, are un randament insuficient, rezultat din multiplicarea următoarelor randamente parţiale: înţelegerea metodei şi a abordării autorului, a terminologiei, a bazei fizice.

Ştiinţa aplicată de creatorii de automobile în proiectele de cercetare şi dezvoltare trebuie neapărat să ajungă până la şofer şi până la roată!

Prof. univ. dr. ing. Cornel STAN
Redactor şef

SUMAR „INGINERIA AUTOMOBILULUI“ NR. 56

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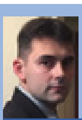
THE INFLUENCE OF THE EXCITATION SIGNAL ON MAGNETORHEOLOGICAL DAMPER DYNAMIC BEHAVIOUR

INFLUENȚA SEMNALULUI DE EXCITAȚIE ASUPRA COMPORTAMENTULUI DINAMIC AL UNUI AMORTIZOR MAGNETOREOLOGIC

REZUMAT:
În contextul îmbunătățirii confortului și a dinamicii vehiculului, sistemul de suspensie a fost dezvoltat și îmbunătățit continuu, în special utilizând amortizoarele magnetoreologice (MR). Amortizorul magnetoreologic poate combina confortul cu conducerea dinamică, deoarece permite adaptarea caracteristicii de amortizare la profilul drumului. Principalul obiectiv al lucrării este acela de a analiza influența semnalului de excitație asupra comportamentului dinamic al amortizorului magnetoreologic în suspensia semi-activă. Influența intensității curentului electric asupra coeficientului de amortizare și a puterii disipate vor fi, de asemenea, studiate. Coeficientul de amortizare fiind variabila de control pentru suspensia semi-activă. În acest sens, autorul a efectuat un set de măsurători experimentale cu un stand de testare amortizoare, special construit și echipat cu echipamente moderne. Rezultatele obținute din determinările experimentale au arătat un confort îmbunătățit semnificativ la utilizarea unui amortizor magnetoreologic, comparativ cu unul clasic, prin faptul că amortizorul magnetoreologic permite modificarea coeficientului de amortizare în funcție de condițiile de drum, menținând astfel contactul permanent între pneu și calea de rulare datorită creșterii forței de amortizare.

Key-Words: *Damper. Intensity. Magnetorheological. Excitation. Experimental. Vehicle*



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NOMENCLATURE

MR: magnetorheological
k_g: the gas chamber stiffness, N·s/m
c_e: the equivalent viscous damping ratio, N·s/m
$F_{MR}(H)$: the controllable damping force, N
F_f: the friction force, N
$\dot{x}_p$: the piston velocity, m/s
F_d: desired damping, N
C: control gain, N·s/m
F: damping force, N
c_{sky}: skyhook viscous damping ratio, N·s/m

1. INTRODUCTION

When the velocity of a vehicle increases, whether we are talking about cars or trains, the vibrations generated by the interaction of the wheel with the road increase significantly and are deeply felt by their body, leading to major problems related to the ride comfort, quality of the travel, stability and the maintenance of the roads. The vehicle suspension has a very important role in controlling its dynamics, being a basic system both for ride comfort while driving and for maintaining/handling the road. The road oscillations are a risk factor for passengers of the vehicles, but also a discomfort at the same time [1][2][3].

The magnetorheological damper is based on rheological fluids, which can change their viscosity when a magnetic field operates on them. A MR fluid consists of a mixture of oil (usually a silicone oil) and microparticles sensitive to the magnetic field (for example iron particles). The MR fluid behaves like a normal liquid when magnetic field is not applied. When a magnetic field is applied to the MR fluid, the particles form chains and the fluid becomes very viscous.

The induced force depends directly on the amount of magnetic flux density developed in the effective fluid flow gap of the MR shock absorber. Its adaptive behaviour has led to a rapid growth in such varied engineering applications as basic insolation of civil structures, vehicle suspensions, and several bio-engineering mechanisms through its implementation in various basic MR fluid devices, especially in MR shock absorbers [4][5]. Through different types of signals applied to the suspension, which represents the excitation of the road, the dynamic behaviour of the suspension can be highlighted [6]. Many suspension systems/methods can be used to isolate the vibrations transmitted, such as vehicle suspension systems, cabin suspension systems and seating suspension systems [7].

The design and analysis of the magnetic circuit is an important stage in the design of the magnetorheological shock absorber. The damping force depends on the intensity of the magnetic field, which is affected by the construction of the magnetic circuit and the associated parameters, as well as the diameter of the piston. Unlike passive suspension, variable magnetorheological shock absorber of semi-active suspension can be effectively controlled in terms of shock absorber stiffness based on required values in a given situation [8][9]. As stiffness and damping emulations in semi-active actuators are coupled quantities the control is formulated to prioritize the frequency control by the controlled stiffness [10].

In an MR damper the piston contains coils capable of providing a magnetic field in the holes. Under these conditions, the piston can be considered as a magnetorheological valve, and the damping is the result of the friction between the magnetorheological fluid and the orifices Figure 1.

The area between the neighbouring poles is a route of natural flow. In the middle region of the pole there is a strangulation of the flow and the saturation in this area must be avoided, because it is a critical area for the performance of the shock absorber [11].

When the coil (located inside the piston) is excited with a square pulse voltage emitted by the electronic control unit, a magnetic field is generated which produces the alignment of the magnetic particles. When the coil is not supplied with electricity, the magnetorheological fluid doesn't magnetize, and the iron particles are randomly dispersed inside the fluid, and the fluid behaves like a conventional hydraulic oil. When the coil is supplied, the magnetic field causes the particles to align in the direction of the magnetic flux. The bond strength between the particles is proportional

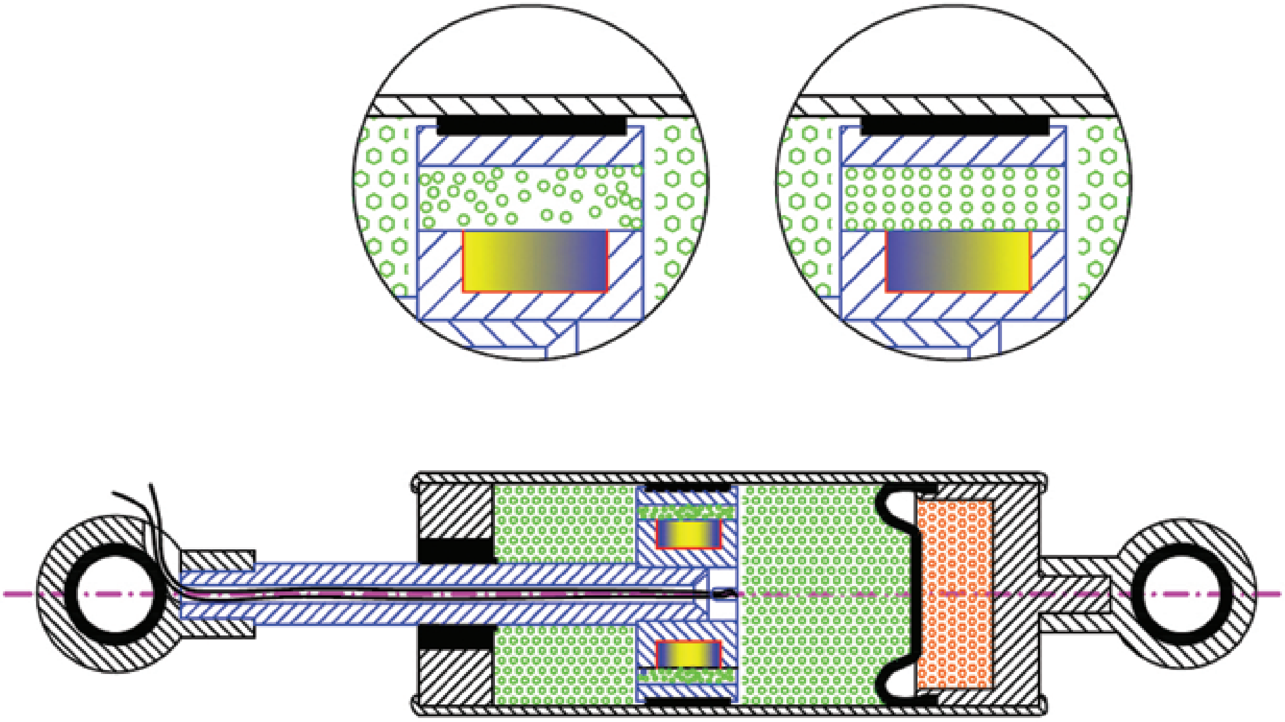

Fig. 1. Schematic diagram of a MR shock absorber

to the strength of the magnetic field. They are positioned transversely to the direction of oil flow, thus limiting the flow of fluid through the piston grooves. The magnetorheological damper can change the damping characteristic much faster compared to a conventional adaptive damper.

Depending on the type of damping force variation mechanism, the dampers can be passive, manually adjustable, adaptive [12]. Using only mechanical valves, passive shock absorbers do not require auxiliary power or control. The manually adjustable ones contain electromechanical actuators, which allow a selection of the predetermined characteristics of the shock absorber valves. Adaptive systems are autonomous and have the capacity to generate force according to road conditions. The available systems are found in several variants, from those with two positions to continuously variable systems. Modification of the stiffness of the suspension, associated with the modification of the damping (so that the relative damping remains unchanged) leads to low variations in the comfort of the vehicle and the safety of ensuring the permanent contact of the wheels with the road. When moving the vehicle, the dynamic forces taken over by the shock absorbers are quite high.

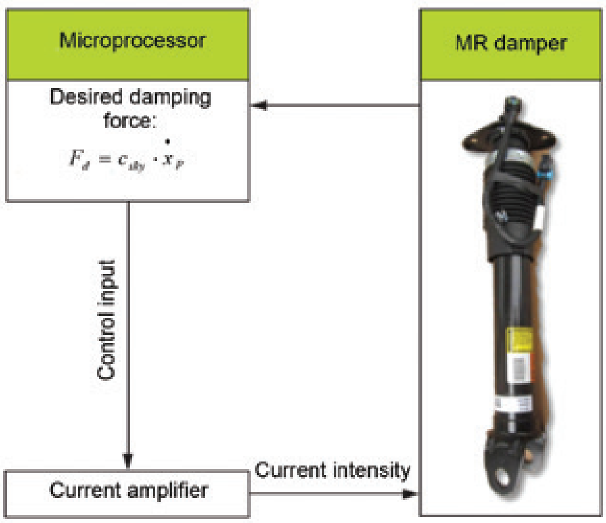

Fig. 2. Skyhook damping force control of an MR damper

There are numerous studies in the literature based on adaptive control methods, which have the role of producing an improvement in the properties of vehicle suspensions [13][14][15][16][17][19].

Electronically controlled active suspensions can substantially improve driving comfort as well as the road holding characteristics, capability of the vehicle. When the load of the vehicle changes, the suspended mass varies within quite large limits. As the load decreases, there is an increase in relative damping, which is essential for the amplitude of the low frequency oscillations. When the suspended mass decreases, the natural frequency increases, favouring the appearance of the resonance phenomenon at the usual travel speeds. If the damping factor is maintained when the load decreases, the comfort at resonance decreases.

2. MATERIALS AND METHODS

2.1 Control strategy

The semi-active control system performance can be generally improved in an active way, without using large energy sources. The necessary external energy needed to generate the desired control forces of an intelligent suspension it is an important problem that needs to be taken in account in the makings of the controller. For obtaining the desired damping force in a controllable area, we can use three main semi-active methods of control that are different: skyhook, ground hook and sky–ground hook. One of the most popular control logics for the semi-active control systems is the control algorithm Skyhook, because this algorithm is very simple to

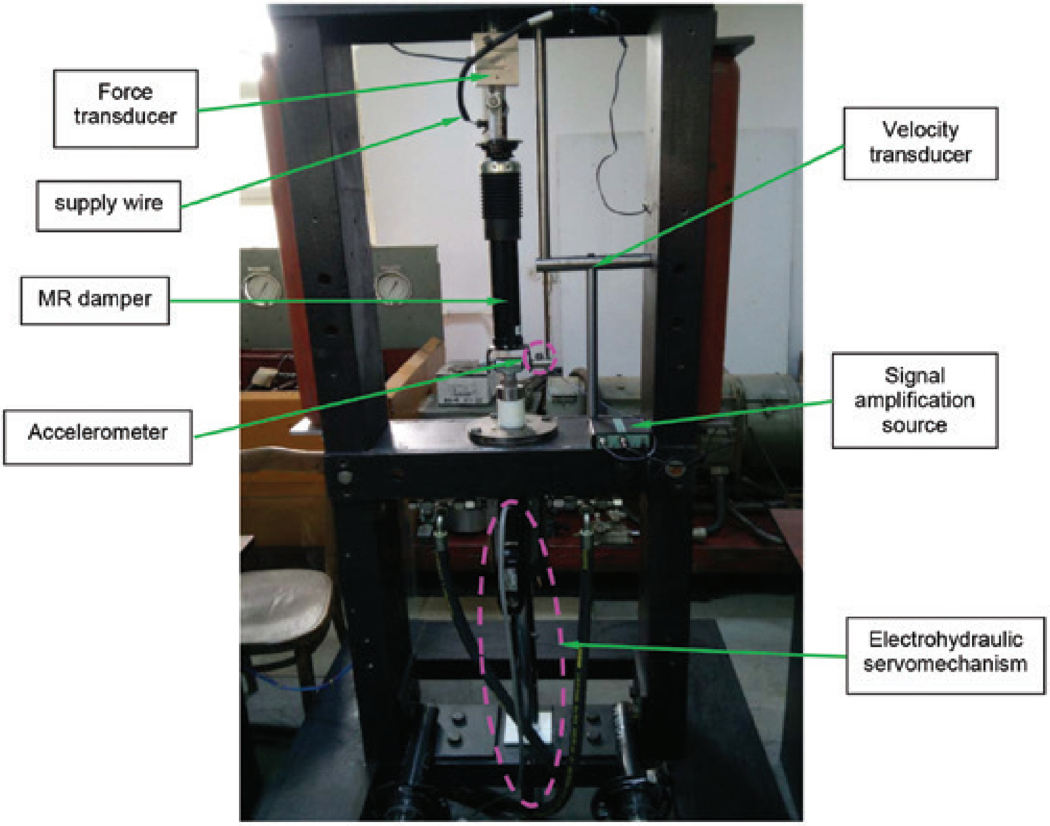

Fig. 3. A part of the installation for testing magnetorheological dampers

Fig.4. Detail regarding the mounting of the shock absorber at the top

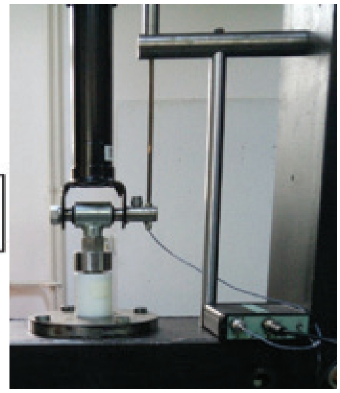

Fig. 5. Detail regarding the mounting of the shock absorber at the bottom

formulate and easy to implement in practice. An example for the skyhook controller appliance, that keeps account of the damping control force for the MR damper it is showed in the Figure 2.

The principle of this approach is to design an active suspension control so that the chassis is "linked" to the sky in order to reduce the vertical oscillations of the chassis and the axle independently of each other [18]. The damping force of the damper can be derived from:

$$F = k_g \cdot \dot{x}_p + c_e \cdot \dot{x}_p + F_{MR}(H) + F_f \qquad (1)$$

The controllable damping force depends on the magnetic field *H*. Generally, to implement the MR damper in the suspension system of the car we require a high damping force in the extension movement and a small damping force in the compression movement. If $\dot{x}_n \geq 0$ the piston of the damper is in extension stroke and $F_d = C \cdot \dot{x}_p$ (C = control gain). If $\dot{x}_p < 0$ the piston of the damper is in compression stroke and F_d = *F* in the absence of the magnetic field [18]. To find a good compromise between comfort and manoeuvrability one way is to shape a skyhook damper. The skyhook damper adapts to the road conditions and minimizes the pitching and rolling tendencies of the automobile.

2.2 Manetorheological dampers test bench

The test bench, designed and made by the author, consists of the main components: electrohydraulic servomechanism, position transducer, force transducer, velocity transducer, accelerometer, hydropneumatics accumulator, MR shock absorber, servo valve, servo cylinder etc. The principle scheme of the installation used for performing the experimental identification is presented in Figure 3 and the details regarding the damper mounting are presented in Figure 4 and Figure 5. For the control of the electrohydraulic servomechanism and for the acquisition of the measured data, a PXI modular platform for industrial test and measurement applications is used, provided with a data acquisition board produced by the National Instruments corporation, assisted by the LabVIEW program produced by the same corporation.

The excitation of the magnetorheological shock absorber is done with a position signal, like to the real operating situation, a signal which, depending on the type of test performed, can be sinusoidal, triangular or compound. The output quantity is the damping force developed by the magnetorheological damper, corresponding to the different load velocities. A high speed piezo ceramic force transducer (MTS) is used to measure the damping force developed by the shock absorber. The velocity of the stroke piston is measured by an inductive contactless transducer (SCHEWITZ).

In the case of electromechanical test stands, the frequency is usually changed using either a DC motor or a speed reducer. Electrohydraulic test systems, much more elastic in terms of control signals, allow easy modification of both sizes of interest. The magnetorheological shock absorber (Delphi) equips the rear axle suspension of the Chevrolet Corvette vehicle.

The electrohydraulic servomechanism is composed from servo cylinder equipped with the proportional distributor and position transducer. The servomechanism subjected to the experimental research was of electrohydraulic type and had the following characteristics: hydraulic motor type: linear, symmetrical, total piston stroke: 200 mm, piston usable area: 7.65 cm^2, electrohydraulic amplifier type: BOSCH OBE, MOOG series D76 or equivalent, type of electronic controller: linear PID, position

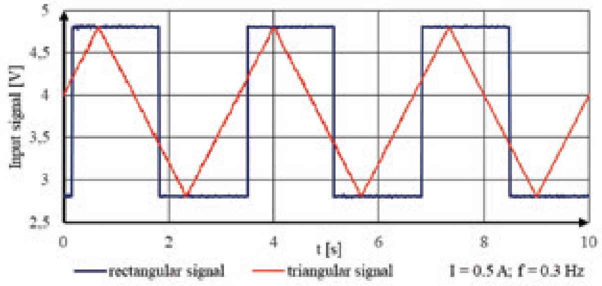

Fig. 6. The variation in time of the signal type for a tested magnetorheological damper

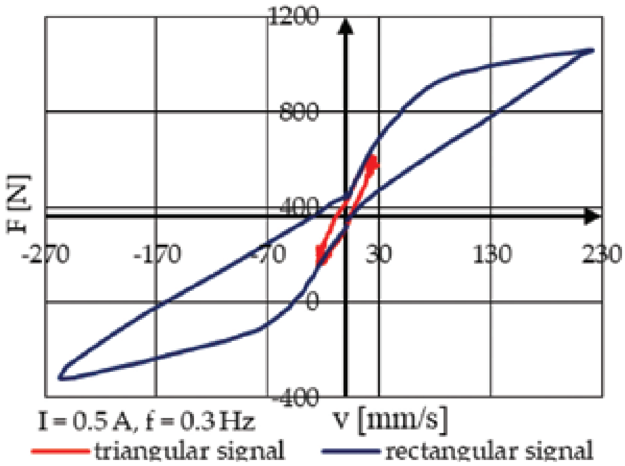

Fig. 7. The damping characteristic of the magnetorheological shock absorber in force-velocity coordinates

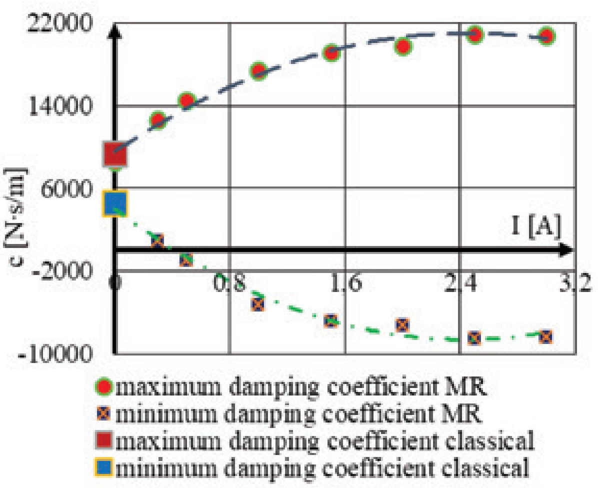

Fig. 9. The maximum and minimum damping coefficient depending on the current intensity, for a magneto-rheological damper

transducer type: inductive, non - contact, or resistive, two - track, rated operating pressure: 21 MPa. To determine the regulation characteristic, the reference signal used was a triangular signal with an amplitude of 9 V and a frequency of 0.02 Hz, which provided the servomechanism with a quasi-stationary operating mode (piston speed was 3.6 mm/s). The sampling frequency was in this case 10 Hz.

The temperature of the oil in the shock absorber and its body varies sufficiently slowly, being the cumulative result of energy dissipation during the test and of the limited cooling possibilities. Temperature certainly influences performance and tends to reduce the damping force for a given speed. Also, the force due to the gas pressure and its corresponding rigidity increase with increasing temperature. Under these conditions, temperature monitoring is required. This can be easily done using a thermocouple, together with the appropriate display element.

3. RESULTS

In this chapter I will present some the experimental results of the tests of magnetorheological shock absorbers, in order to analyse their dynamic behaviour. A triangular and a rectangular signal were chosen as excitation signals. The value of the electric current intensity is 0.5 A, and the excitation frequency is 0.3 Hz Figure 6. The rectangular signal characterizes the operation of the shock absorber in heavy driving conditions, and the triangular one in light driving conditions.

The damping characteristics of the damper for the two types of signals

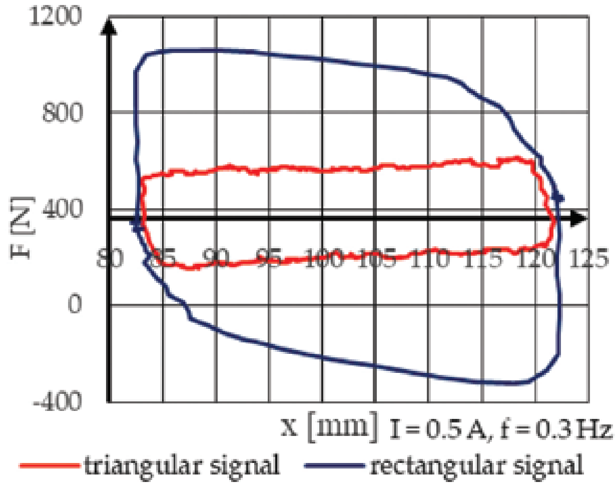

Fig. 8. The damping characteristic of the magnetorheological shock absorber in force-displacement coordinates

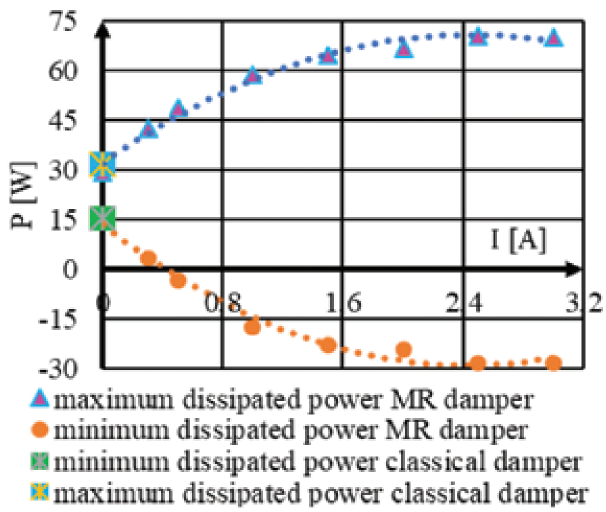

Fig. 10. The maximum and minimum dissipate power depending on the current intensity, for a magneto-rheological damper

are shown in Figure and 7 and Figure 8. We find that the damping force developed by the magnetorheological shock absorber is higher compared to that developed by the classic shock absorber. We also notice that depending on the type of signal, the hysteresis loop also changes. Experimental research has determined the actual damping characteristics and revealed the influence of current intensity on these characteristics.

Figure 9 shows the variation of the maximum and minimum damping coefficient depending on the current intensity, for a magnetorheological damper, for a sinusoidal signal with a frequency of 0.5 Hz.

We notice how the magnetorheological shock absorber changes the value of its damping coefficient depending on the value of the electric current intensity. After a higher value of the electric current intensity, over 3 A the trend shows that the value of the damping coefficient of the magnetorheological shock absorber tends to saturate Figure 9.

Figure 10 shows the dissipated power corresponding to the maximum forces, for different values of the electric current intensity for a magnetorheological damper, considering a piston speed of approximately 60 mm/s and an input sinusoidal signal at a frequency of 0.5 Hz. Over 3 A the tendency is for the dissipation power to saturate as well. The law of variation for the damping coefficient, respectively for the dissipated power by the magnetorheological shock absorber, as a result of the viscous friction approximates a polynomial.

The dissipated power curve, depending on the current intensity, shows a faster variation up to 1 A, then it starts to have a slower variation. The power dissipated by the magnetorheological shock absorber is higher compared to that of the classic shock absorber.

The experimental research undertaken allowed to determine the real dynamic characteristics of the shock absorber and to identify the influence of the parameters on these characteristics.

4. CONCLUSIONS

Devices that use MR fluids require low power, below 50 W: 12-24 V and 1-2 A [11][18]. Conventional batteries can easily provide this power. This is also confirmed by the results of the experimental research.

Passive suspensions are digitally controlled, thus becoming essential comfort elements of luxury and sports cars. Due to the high cost, active suspensions are mainly used for military vehicles and high-end luxury class vehicles. Semi-active suspensions are beginning to become economically feasible, as they achieve a trade-off between price and performance, offering comfort close to that of an active suspension with an acceptable cost and reasonable fuel consumption. Among the semi-active suspension variants, the magnetorheological ones are also the most used, because they are cheaper, and the magnetorheological fluid can be controlled more easily, compared to the electrorheological one.

The results obtained from the experimental determinations show a significantly improved comfort when using a magnetorheological shock absorber, compared to a classic one, by the fact that the magnetorheological shock absorber allows to modify the damping coefficient according to the road conditions, thus maintaining the permanent contact between the tire and the road increase in damping force. Following experimental research, it was found that the rectangular input signal demands more damping compared to the rest of the signals. Modification of the stiffness of the suspension, associated with the modification of the damping (so that the relative damping remains unchanged) leads to low variations in the comfort of the car and the safety of ensuring the permanent contact of the wheels with the road. When moving the car, the dynamic forces taken over by the shock absorbers are quite high.

The variation of the damping coefficient depending on the intensity of the electric current shows that it does not vary linearly, but parabolically, the damping coefficient reaching about 21000 N·s/m, at a current of 3 A. Analysis deduced from the variation of the damping coefficient, the damping force changing its value depending on the value of the damping coefficient, which changes due to the viscosity of the fluid.

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PREDICTION MODEL FOR SEDAN CLASS VEHICLE BRAKING DISTANCE ON A FLAT SURFACE USING EXPERIMENTAL BRAKING TESTS FOR DIFFERENT ROAD SURFACES

MODEL DE PREDICȚIE PENTRU DISTANȚA DE FRÂNARE A VEHICULELOR DIN CLASA SEDAN FOLOSIND TESTE DE FRÂNARE EXPERIMENTALE PENTRU DIFERITE SUPRAFEȚE DE RULARE

REZUMAT:
Distanța de frânare a vehiculului este un parametru critic atunci când vine vorba de reconstrucția accidentelor. Determinarea distanței efective de frânare a vehiculului depinde de o serie de parametri, cum ar fi uzura anvelopelor, suprafața drumului, tipul vehiculului și masa și sistemul de frânare a vehiculului. Această lucrare prezintă un model de determinare a distanței de frânare bazat pe situații din lumea reală în comparație cu curbele teoretice de frânare. Pentru a dezvolta acest model, testele experimentale trebuiau efectuate pe diferite suprafețe precum zăpadă și asfalt, folosind același tip de vehicul și studiind parametrii dinamicii ai acestuia. Pe baza testelor efectuate, a fost obținut un nou model matematic folosind o funcție polinomială de ordinul doi, pentru fiecare tip de suprafață a drumului.

Key-Words: *Vehicle, Braking distance, Safety, Mathematical formulas, Experimental tests*


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1. INTRODUCTION

The modern vehicles focus on improving performance and safety, reason why research on the braking system are in a continuous motion of development since the braking system directly affects the safety of the passenger [1][6][7]. The braking distance of a vehicle is most important, especially in the case of accident reconstruction where the travel distance of the vehicle is crucial in solving some cases [10][18]. Braking distance prediction is also important in the field of the new modern active safety systems such as the Autonomous Emergency Braking [2]. These safety systems can quickly detect potential threats on the road such as pedestrians or animals and brake the vehicle in order to avoid a collision [1]. Emergency braking systems are even more critical in the case of heavy vehicles where the stopping distance is greater due to the low declaration rate of these types of vehicles [23][16]. Henderson and Cebon [4] measured the pneumatic systems for heavy vehicles and discovered a reduction of 15% and 22% of the stopping distance using a system developed by Cambridge Vehicle Dynamics Consortium.

Tires are also a key factor for evaluating the braking distance of a vehicle. In Europe, the tire label on each tire, indicates the grade for a few parameters that include the rolling resistance, the wet grip performance and outside road noise [8].

Braking a vehicle requires attention not only to the dynamic part of braking [11][20], but also to various additional physical effects that need a clear understanding of what is their influences on the vehicle behavior when braking in order to achieve a better performance and safety [3][15].

There are systems developed to control the tire slip. Using this system, the braking forces can be adjusted accurately in various and multiple operating conditions and also various road conditions. Maintaining a specified value for tire slip on each wheel, the braking force values can be maximized in order to obtain the shortest stopping distance possible or can be optimized for greater vehicle stability [5][18]. In our study, we focused on the braking and stopping distance of the vehicle by the means of experimental testing and creating an alternative model that will be used to quickly estimate the stopping distance of a specific vehicle. For this study, we will be using only one type of vehicle, a sedan class car and conduct braking tests on different surfaces and velocities using the same parameters for this vehicle.

2. PRESENT METHODS OF DETERMINING THE BRAKING DISTANCE OBJECTIVES

The present formula used to determine the braking distance relies on couple of parameters such as velocity and road friction coefficient:

$$Sf = \frac{v_0^2 - v_f^2}{26 \cdot \varphi \cdot g} \quad (1)$$

where Sf is the braking distance [m], v0 is the initial velocity [km/h], vf is the final velocity of the vehicle [km/h], f is the friction coefficient between the tire and the road and g is the gravitational acceleration. Tire-road friction coefficient represents the level of adhesion between the contact pattern of the tire and the surface of the road [16]. To get the vehicle stopping distance, the driver's reaction time (0.8- 1 seconds) [9] needs to be added, thus the formula will result in [17, 22]:

$$Sf = v \cdot t + \frac{v_0^2 - v_f^2}{26 \cdot \varphi \cdot g} \quad (2)$$

The further issue with this formula is that the friction coefficient needs to be calculated or chosen from a table of experimental determined values such as the one shown below [20]:

Table 1.
Road surface coefficient values [20]

Road condition	Friction coefficient
Dry quality road	0.7 - 0.8
Dry pavement	0.5 – 0.7
Wet road	0.45 – 0.6
Snow covered road	0.2 – 0.4

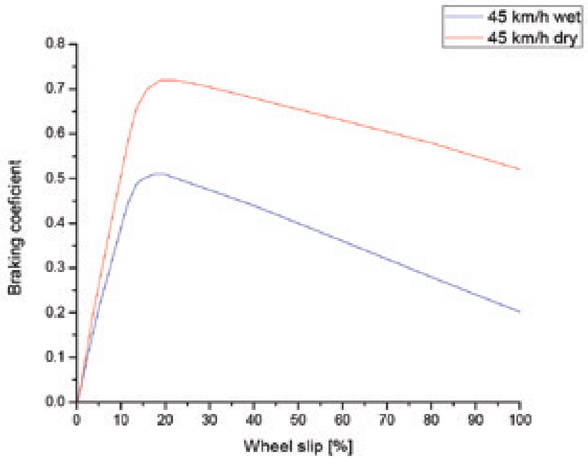

Fig. 1. Braking coefficient vs. slip [19]

The braking tire-road coefficient and the wheel slip are strongly connected, influencing each other as the graph below shows [19].
The maximum braking coefficient translates into the maximum tire grip force that can be obtained on the road without slipping. The tire-road coefficient can also be calculated using formula 3. It depends on the vehicle deceleration in regards to the gravitational acceleration.

$$\varphi = \left|\frac{a}{g}\right| \tag{3}$$

Where *a*, is the vehicle's deceleration rate. Also, the estimation of the road friction coefficient is a potential useful parameter for modern active safety systems [14]. Paul and Velenis developed an algorithm in order to estimate the critical conditions when the front or rear of the vehicles wheels approached the limit of adhesion in the braking phase and can be incorporated by brake control systems such as the ABS [12]. Another way of determining the friction coefficient in real time is by using an extended Kalman filter and a Bayesian decision making algorithm [13].
The vehicle mean deceleration can be calculated using the formula.

$$a = \frac{\Delta v}{\Delta t} \tag{4}$$

The deceleration of the vehicle can be obtained using various methods. The method chosen to collect velocity data for our research was by using a GPS system, comprised of a laptop, special software and two sensors, model Garmin 18x that can track multiple satellites for fast accurate positioning and velocity estimation at a high acquisition frequencies.
Below is a graph showing the braking distances on various surfaces.

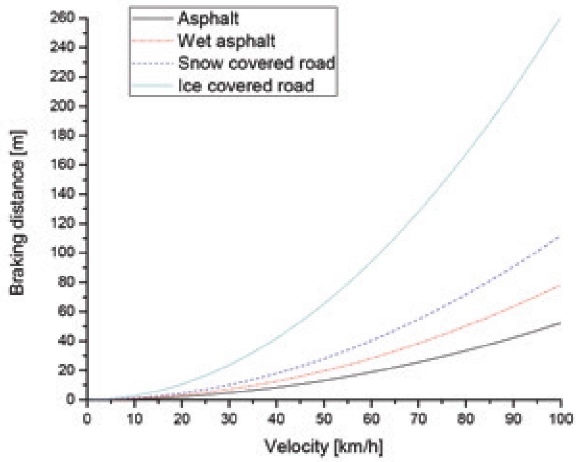

Fig. 2. Graph showing the braking distance on different surfaces

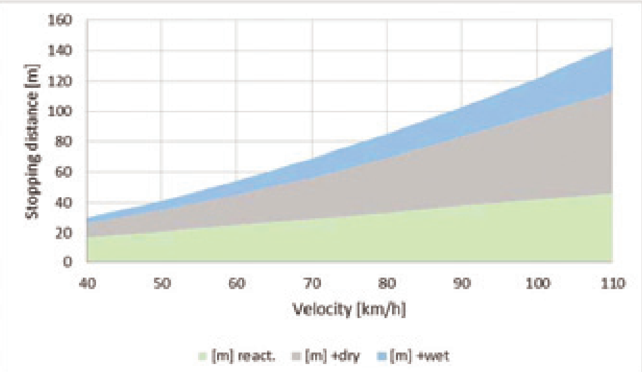

Fig. 3. Graph showing the stopping distance for an average family vehicle [21]

In figure 2 there are presented the braking curves determined using formula (1). For the calculus, the friction coefficient was chosen for each surface from table 1. This is a theoretical calculation and an ideal braking distance result. In practice, the friction coefficient on different surfaces may vary from the theoretical model, so the scope of this study was to determine several curve models based on real experimental braking tests in order to have a more accurate representation of the braking distances on various surfaces. A study shows that for a family car (sedan class vehicle) the braking distances vary when the reaction time is added compared to those shown in figure 1 [21]. Here we can see different stopping distances for various velocities including the reaction time of the driver. Depending on the speed, the reaction time differs, from 17 m at 40 km/h up to 46 m at a velocity of 110 km/h.

3. OBJECTIVES

Objectives for this paper were:
• To conduct experimental braking tests on a flat road and on different surfaces using the same type of vehicle and parameters.
• To use the data obtained from the experimental tests in order to determine an alternative, simpler formula to calculate the braking distance of a specific type of vehicle on different road surfaces.
• To validate the model using theoretical curves.

4. EXPERIMENTAL TESTING METHOD

The basic setup used to perform the experimental tests is presented in figure 4. The vehicle was equipped with two GPS sensors, model Garmin 18x capable or recording with a frequency of 5 Hz, with 20 millisecond increments, from 20 ms up to 980 ms with 1 microsecond accuracy,

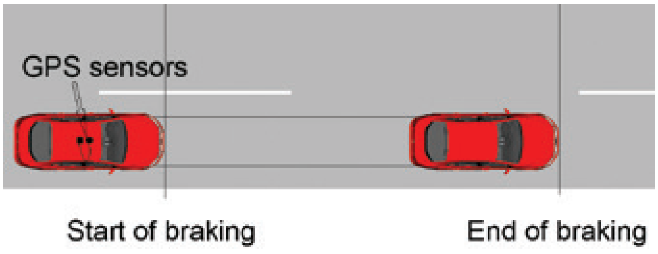

Fig. 4. Experimental testing method

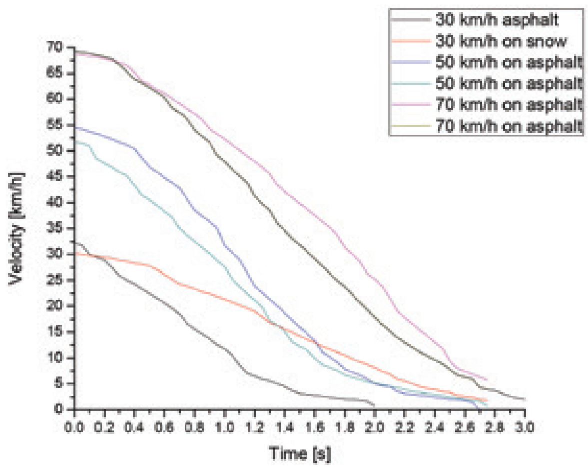

Fig. 6. Braking velocities from GPS data

mounted on the roof of the vehicle relative to the center of mass position that are used to record the variation of the vehicle's velocity. The vehicle was a sedan class equipped with ABS, ESP and ASR systems. The braking system is comprised of ventilated discs with caliper on the front wheels and normal braking discs on the rear. Winter tires were used with the dimensions 195/65 R15 T with a 25% - 50% wear.

A total number of 33 braking tests were conducted – minimum tire degradation, recommended tire pressure values -, of which 11 tests conducted on asphalt, 11 on wet asphalt and 11 on snow surface. Some of the data is presented in the next graph. The velocity values vary in time and are presented from the moment when the vehicle braking was initiated to the moment the vehicle reached full stop (0 km/h).

In figure 5 some curves from selected tests are presented with the scope to clarify the variation of the vehicle's velocity. These tests represent braking at 50 km/h on snow and asphalt surfaces. More braking tests were conducted at different velocities: 30 km/h, 50 km/h and 70 km/h. Some of the test results are presented in figure 6.

From the recorded data, the traveled distance of the vehicle was calculated using the formula 5.

This formula describes the integration of the velocity over time:

$$d(t) = d_0 + \int_0^t v dt \tag{5}$$

The distance calculated is the actual braking distance of the vehicle. It is considered from the moment the velocity is starting to decent until it reaches full stop (0 km/h).

5. TEST RESULTS

Using the recorded data from the experimental tests, the braking distance

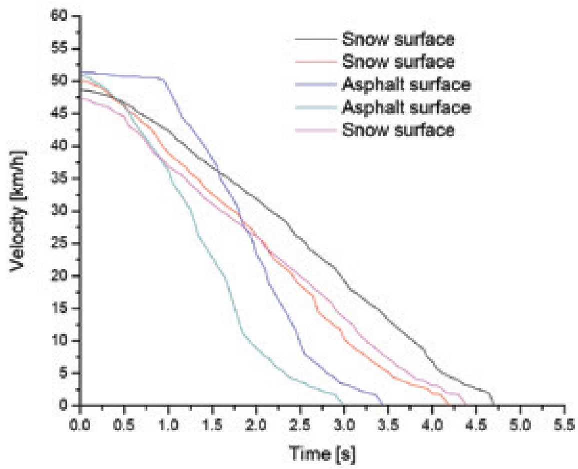

Fig. 5. Velocity graph resulted from GPS data

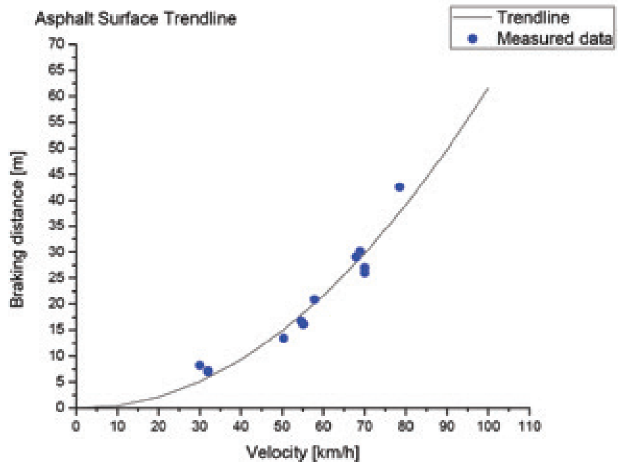

Fig. 7. Graph showing the measured braking distance values and the interpolation trend line for asphalt surface

and velocity curve was obtained for every brake velocity tested. Multiple tests results (velocty and braking distance) were plotted for the same surface in order to create a polynomial trendline. Three surfaces were considered relevant within the scope of our experimental case: asphalt, wet asphalt and snow surfaces.

In figure 7, a number of 11 asphalt surface tests are presented for different velocities. By using the polynomial function of the second order a trend line was obtained representing the determined braking distance curve. This polynomial function is considered here as an alternative braking distance solution. In a similar way, trend line for wet asphalt was obtained, which is presented in the figure 8. For this scenario, 5 tests at different velocities were used to obtain a polynomial function of the third order.

For snow surface, the results are shown in figure 9. In this figure the trend line was obtained from 6 tests using a polynomial function of the second order. The previously resulted curves will be validated by comparison with the theoretical calculated braking distance curves.

6. PROPOSED BRAKING DISTANCE MODEL EQUATIONS

Using the polynomial functions, equations were determined. These are considered as an alternative way of calculating the braking distance of a

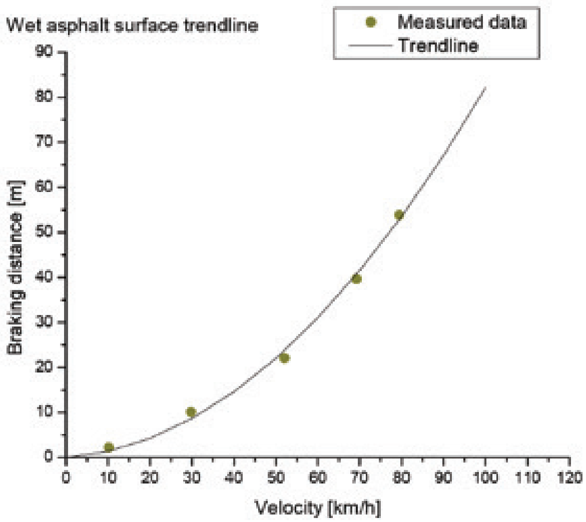

Fig. 8. Graph showing the measured braking distance and the interpolation trend line for wet asphalt

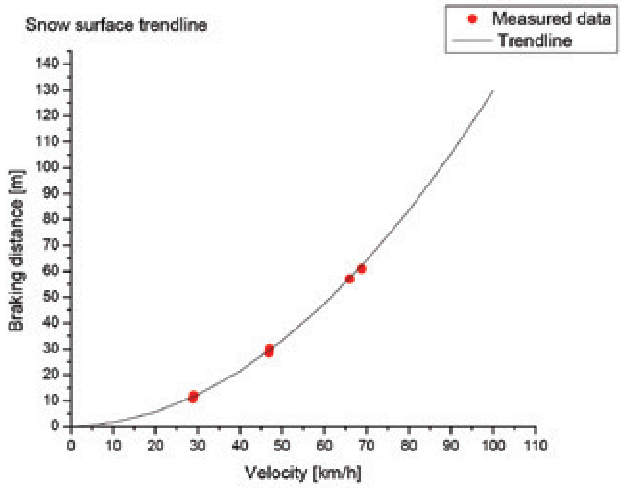

Fig. 9. Graph showing the measured braking distance and the interpolation trend line for snow surface

vehicle. The vehicle velocity is expressed in km/h.
So, for asphalt surface, the formula determined is:

$$B_{da} = 0.0064 \cdot v^2 - 0.024 \cdot v \quad (6)$$

This formula calculates only the effective braking distance of the vehicle. If the reaction time formula is added, we can calculate the effective stoping distance of the vehicle.

$$S_{da} = (0.0064 \cdot v^2 - 0.024 \cdot v) + [(v \cdot t_r)/3.6] \quad (7)$$

Where v is the velocity of the vehicle [km/h] and tr is the reaction time [s]. The reaction time of the driver is considered around 1 second, where the human reaction is 0.8 seconds and 0.2 seconds is the braking system lag.
From the tests, on wet asphalt surface, the formula was determined with the polynom of the third order:

$$B_{dwa} = 0.0076 \cdot v^2 + 0.0611 \cdot v \quad (8)$$

Also adding the reaction time will result in the total stopping distance of the vehicle:

$$S_{dwa} = \left(0.0076 \cdot v^2 + 0.0611 \cdot v\right) + \frac{v \cdot t_r}{3.6} \quad (9)$$

In a similar way for snow surface, using the trend line polynomial function, the resulted equation is:

$$B_{ds} = 0.0127 \cdot v^2 + 0.0273 \cdot v \quad (10)$$

As before, this formula calculates only the braking distance and in order to obtain the stopping distance, the reaction time needs to be added to the formula.

$$S_{ds} = (0.0127 \cdot v^2 + 0.0273 \cdot v) + [(v \cdot t_r)/3.6] \quad (11)$$

7. VALIDATION OF THE MODEL WITH ANALYTICAL MODEL

Validation of the model was done by comparison with theoretical calculation curves. Errors were calculated and the relative error were obtained.
The equation is based on the absolute mean defined by this formula:

$$\Delta m = |\overline{m} - m_i| \quad (12)$$

Where m - the measured size, $\overline{m}$ - the absolute value of the magnitude, i - the number of measurements. The absolute mean error Δm is calculated with the relation:

$$\Delta\overline{m} = \frac{\Delta m_1 + \Delta m_2 + \ldots + \Delta m_i}{i} \quad (13)$$

The relative error is defined as the ratio between absolute error and absolute value of exact size:

$$\frac{\Delta\overline{m}}{\overline{m}}(\%) = \frac{\Delta m}{\overline{m}} \cdot 100 \quad (14)$$

The theoretical calculations were obtained using formula (1) and with a friction coefficient that matched the ones from the trend line of the experimental tests. For asphalt, the friction coefficient resulted was 0.65. A graph was obtained for the range velocities of 0 to 100 km/h (figure 10). It can be seen that the model and the theoretical calculation match with an average relative error of 2.12% and a minimum relative error of 0.01%. The curves of both the model and the equation have a similar pattern and overlap giving the model a valid use across all tested velocities. The accuracy of our model is 97.88% for velocities up to 100 km/h and 99.4% for velocities between 50 km/h and 100 km/h.
In the figure 11 the similar method was used for wet asphalt.
In this comparison, the friction coefficient obtained was about 0.5 corresponding to a wet asphalt surface. It can be seen that the model and the theoretical formula match with an average relative error of 3.55% with a minimum of 0.13%, giving this model a 96.45% accuracy for velocities up to 100 km/h and an accuracy of 99% for velocities between 50 km/h and 100 km/h. This error is minimal and it is to be considered valid. The final model validation was for snow surface and it is presented in the figure 12. Also, for this graph, the theoretical calculation revealed a friction coefficient of 0.3, corresponding to a snow surface. The model for this case is the most accurate (98.97%) and matches the theoretical model, having a relative error of only 1.03% on average with a minimum of 0.02% for velocities up to 100 km/h and an accuracy of 99.73% between 50 km/h and 100 km/h. The curves match up and make a good representation of the functionality of the model.

8. CONCLUSION

In this study, a fast and highly accurate braking distance prediction model – based on experimental testing - was developed through proposed equations and validated successfully by means of comparison with the

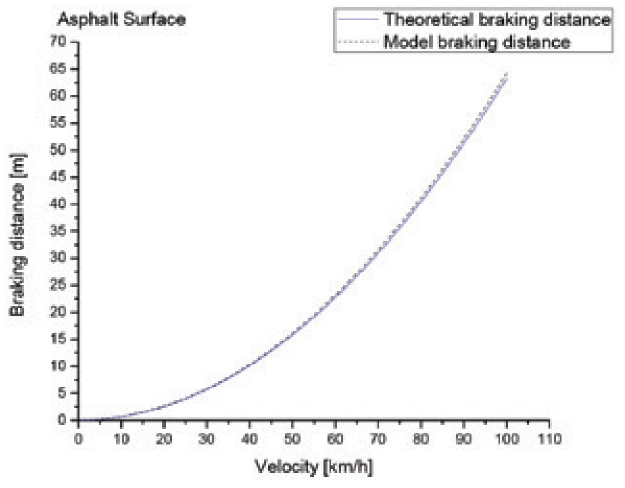

Fig. 10. Graph showing the comparison between the theoretical calculated braking distance and the model formula for asphalt

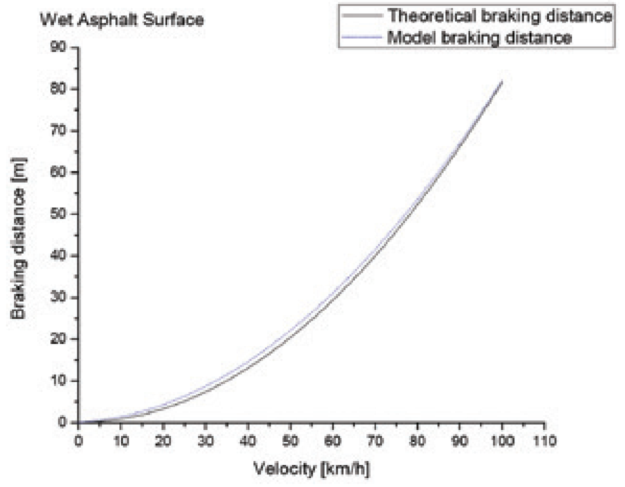

Fig. 11. Graph showing the comparison between the theoretical calculated braking distance and the model formula for wet asphalt

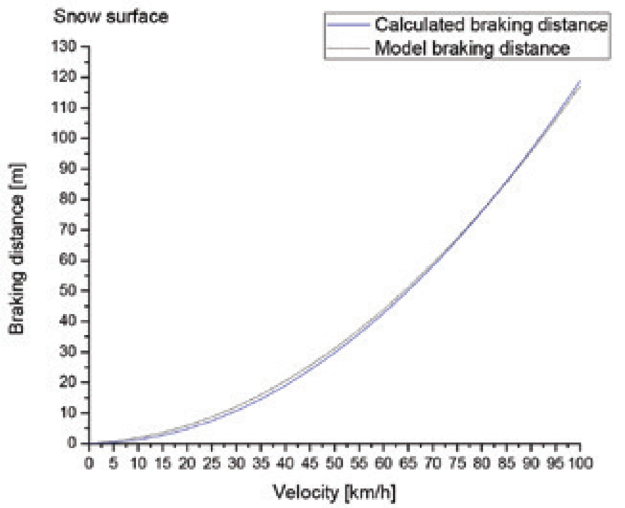

Fig. 12. Graph showing the comparison between the theoretical calculated braking distance and the model formula for snow

theoretical model. The accuracy of the model has been calculated and revealed that for the surfaces tested the model is most accurate at the velocities between 50 km/h and 100 km/h.

For asphalt, the accuracy in that range is 99.4%, for wet asphalt it is 99.0% and for snow the accuracy is 99.73%, while for the entire range, starting 10 km/h up, the accuracy values are as follows: 97.88% for dry asphalt, 96.45% for wet asphalt and 98.97 % for snow conditions.

It is to be considered that the proposed model presents high accuracy within the limits and scope of our study, regarding the vehicle class, road surface and velocity range tested, with the advantage of quick calculation for the specific friction coefficients used.

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IDENTIFYING THE FACTORS INFLUENCING NEW PRODUCT DESIGN AND DEVELOPMENT USING THE MODULAR PRODUCT PLATFORM IN THE AUTOMOTIVE INDUSTRY

IDENTIFICAREA FACTORILOR DE INFLUENȚARE A PROIECTĂRII ŞI DEZVOLTĂRII PRODUSELOR NOI FOLOSIND PLATFORME MODULARE DE PRODUCȚIE ÎN INDUSTRIA DE AUTOVEHICULE

REZUMAT:
Procesele de proiectare și dezvoltare a noilor produse în industria de autovehicule trebuie să dacă față la numeroase provocări. Una dintre strategiile utilizate în acest context este aceea de a folosi platforme modulare. Cu toate acestea, în industria iraniană de autovehicule metoda nu este folosită de mult timp, iar factorii care o afectează încă nu sunt pe deplin determinați. În acest studiu, bazat pe o metodă de cercetare calitativă, autorii au încercat să identifice aceste componente. Rezultatele studiului întreprins arată că patru componente au un effect important: Dezvoltarea tehnologică; Dezvoltarea structurii produsului, Strategia adoptată pentru producție și Dezvoltarea organizațională. În consecință, se recomandă ca orice proces de proiectare și dezvoltare a unui nou produs în industria iraniană de autovehicule să țină cont de aceste direcții prioritare.

Key-words: *modularity, modular platform, product architecture*

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NOMENCLATURE
NPD – New Product Development
R&D – Research and Development

1. INTRODUCTION

Increasing technology changes, market competition and shortening product life have led companies in various industries to innovate and deliver new products at a faster rate, more efficiency and quality (El Maraghy et al., 2013). Therefore, customers are looking for newer, more advanced products that fit their needs (Kotabe and Kothari, 2016). Nowadays companies have little ability to compete without presenting new products. Without a new product design and development, it would be impossible to increase market share and profitability (Mates et al., 2008). The process of designing and developing new product is one of the core capabilities of organizations. The process of designing and developing a new product is a knowledge-driven operation and organizations need sufficient knowledge and information to succeed (Mohammadi et al., 2018). The new product design and development process is a procedure in which an organization utilizes all of its resources, capabilities in the form of multi-purpose teams to create a new and innovative product or to develop an existing product (Morgan and Berthon, 2018).

So that product development is seen as a key process for improvement and reorganization. The expanding scope of new product design and development research has expanded to such an extent that it has led to the creation of a broad body of extensive research in the field of production management knowledge (Zhang et al., 2017). According to Sheng et al. (2016) creating a competitive new product requires the right balance between three elements: the ideal product innovation process, effective leadership from top management, and a supportive work environment.

The main purpose of this article is to identify the main factors influencing the design and development of a new product using the platform module in the Iranian automotive space. Therefore, the researchers recognized the necessity of creating a comprehensive explanation and localizing it based on the evaluation of the opinions of authorities and internal experts. As such, the present paper systematically reviews and analyzes existing literature on modular platform product design and development factors, based on research achievements published during 1996 to 2019 in internally and externally validated classified and arranged databases. Identifying key components of product development by using modular platform in Iranian automobile industry has identified and delineated the dominant conceptual framework in these researches based on the opinion of domestic and Iranian experts.

2. THEORETICAL BASIS

In this section of the paper, we review the theoretical foundations and background of the research. The relationship among strategy, structure, and product development should be considered in the context of multiple and related concepts such as: architecture, functionality, family and platform product modules. Product function means what the product has the ability to do (Ulrich, 1995). The module is part of the functional unit of a product (Baldwin et al., 1997), (Lundqvist et al., 1996), (Wilhelm, 1997). A module is defined as a structure independent of a larger system with a specific function (Otto, 2016). Modularity can address standards, including specifications, design planning, manufacturing process, maintenance and service of a product (Wan et al., 2019). Product architecture is the function of a product being assigned to its physical parts (Ulrich

Table 1. Main components and their corresponding subcategories

	Main components	**Sub-Components**
Successful components of new product design and development using a platform module	Technology development	Technical solution Product architecture
	Product structure development	Product performance Architecture
	Strategy development	Product idea Product basket Specializing in contractors
	Organizational development	Organization with product design and development process capability

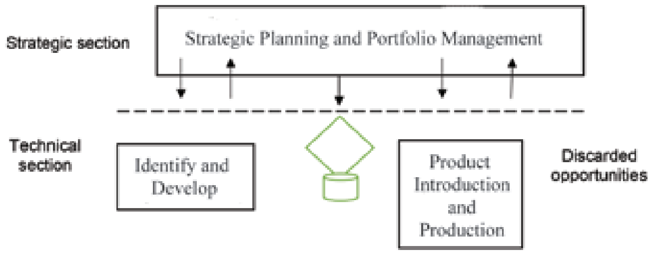

Fig. 1. Competitive new product design and development process (Sheng et al., 2016)

et al., 1994). In 1995, Ulrich explored the relationship between product architecture and product strategy and tried to explain it in product development. Also, the concept of platform has received a lot of attention to the relationship between product development and payment operations management (Wheelwright et al., 1992), (Cusumano et al., 1992).

From a production and assembly standpoint, the platform means focusing on the sharing of machines, tools, and assembly lines (Muffatto et al., 1998). The platform is also able to structure the organization (Calabrese, 1997). The product platform also has the capability to adapt to open architecture, in other words, the product platform is capable of responding to mass production with customization (Zhang et al., 2017). Examination of key success Costa and Jongen (2016) studied research using reference groups in the process and conducted their research based on the Cooper model. They also identified eight steps for product development. Looking at the past, especially in recent years, confirms the existence of a rich record of research trends in the concept of new product design and development. According to Peterson (2005) and Sheng et al. (2016), creating a competitive new product requires the right balance between three elements: the ideal product innovation process, effective leadership from senior management, and a supportive work environment. The model presented in Figure 1, which can be considered as an internal part of the hypothetical engine of innovation, assists in coordinating and balancing the mentioned elements by utilizing strategic management, portfolio management and technical issues.

Today, most organizations are looking for competitive advantage factors and developing new products helps organizations maintain their competitive position (Radfar et al., 2016).

A study of the factors affecting the success of NPD projects in the manufacturing industries of several advanced countries such as the United States, Canada, Germany, and Belgium by Wang (2018) showed that: 1) the use of multifunctional teams and the focus on dedicated teams; 2) Using research market 3) Market test, initial evaluation of product and production as well as end customer reviews; 4)The quality of the 2 and 3-degree advertising, or the degree to which the company is present in international markets, can be seen as influencing the success of NPD projects. In-house research has also taken into account the factors affecting the success of new product design and development.

3. RESEARCH METHODOLOGY

The present study is implemented in two general stages: First, reviewing the literature and identifying the most important elements (factors, indicators, measures, etc.) in the success of new product design and development using modular product platforms. Second, semi-guided interviews with automotive experts in the phenomenon under study (including managers and car designers) that commented on identified items. A content analysis was used to evaluate the views. In general, content analysis can be done with three categories: approach, evaluation and correlation. The interviewees were selected by purposeful (directional sampling) and snowball method. Given that Kuala considers the sample size between 1 and 2 to be appropriate for such research. While studying the results of the theoretical studies, the researchers were finally able to access the 17 experts in the field of new product design and development in the automotive industry with at least five new products in the past 5 years. The data collection process at this stage was that the interviewers first read the metrics identified in the research literature and then explained, completed, or critiqued them. The interviews continued until the theoretical saturation. The interview time of the experts was this study was at least 80 and 140 minutes maximally.

4. DISCUSSION

After examining the categorical content in the form of the aforementioned process, the initial codes fall into four main categories: (1) technology development, (2) product structure development, (3) strategy development, and (4) organizational development. Table (1) shows the results. These are, in fact, the important components of the success of the new product design and development process in the automotive industry and are illustrated in Figure 2. Considering the structure shown in Table (1) and Figure (2), each of the main categories will be described below.

Table 2. Selected Codes for Technical Development Categories

Main-Components	Sub-Components	Selective codes
Technology Development in Modular Platform	Technical solution Product architecture	Partial or total change in product technology The prototype includes all features Pay attention to the expense incurred in the prototype The design of the product is virtual and varied Product testing in terms of customer feedback on the use of new machines

4.1 Technology development

When designing and developing a new product with the use of a platform module everywhere, it is always the first thing that comes to mind when changing production systems and creating a product with „higher capabilities". But what is important is that technical development is not limited to such decisions. As shown in table (2) of the selective codes for the category of technology development (6 items), these activities have a very broad scope.

4.1.1 Partial or total change in product technology

New product design and development is a gradual issue that has been mentioned in the studies of Liu et al. (2005) and Ozer (2006). In general, what most experts in the technical development field were saying is: are you looking for a partial product development? Or is your goal to fully develop and launch a highly reputable product? For example: Automakers have stated that: „For some models only the engine and chassis have been modified and in some cases even the car suspension, transmission and body have undergone changes, so you must purchase new equipment and consider a lot of requirements".

4.1.2 The prototype includes all features

Prototype placement in new product design and development is a topic discussed in the studies by Petersen et al. (2005). The manager said: „If we are going to spend money and offer a specialized product, it should be a perfect product. We can't market based on an incomplete sample. The risk of such an investment is very high".

4.1.3 Pay attention to the expense incurred in the prototype

One of the important features is the design and development of a new product using the platform module in cost discussion, and much of it is related to the prototype (Matsui et al., 2007). „We've been able to reduce production costs significantly by using a very simple in-line approach!" says product development experts. „But in order to reduce the price of the product must not affect the customer's trust and attractiveness of the product market. We introduced the product with new design, new name and price".

4.1.4 The design of the product is virtual and varied

In the new product design and development approach using platform modules, a specialized software can be used to design the production processes prototypes, simulate and correct them (Lai et al., 2012). According to one of the interviewed executives, new product design has a huge impact on its branding and customer attraction. It may be possible to market a same product in several different designs and the customer will evaluate them all in one way.

4.1.5 Test product in terms of customer feedback on the use of new machines

One of the important steps in launching a product pilot market is to test the latest potential problems and try to deliver an optimal new product (Marion, 2009). In this order, one of the executives with large experience says: „no matter how many new products you market, it's important how much your customers understand the new product differences". The use of new machines is a valuable competitive advantage in any industry (To et al., 2009).

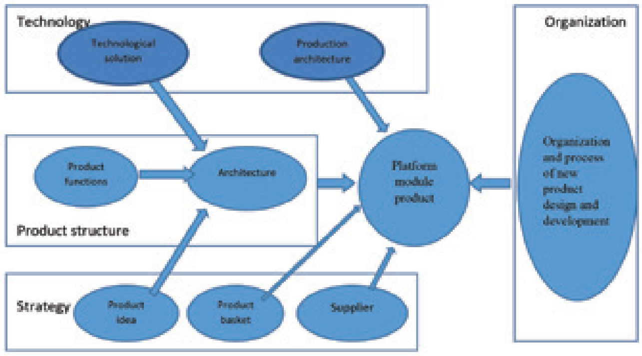

Fig. 2. Components of the new product design and development using the platform module

4.2 Product structure development

The development of product structure further implies that the nature and outlook of the company should be appropriately developed so that the customer's mind is ready for acceptance of the new product (Millson and Wilson, 2006).

For this purpose, four selective codes have been proposed which can be seen in Table (3).

4.2.1 The degree of product difference from competitors

What is most important in designing and developing a new product using a platform module for the customer is its uniqueness (Ozer, 2006). Customers are always looking for something that is different (not necessarily the best). Create a marketplace that looks more customer-friendly than competitors.

4.2.2 Production of homogeneous or heterogeneous products being different

Another crucial aspect of platform module production is the question of whether to upgrade to the same products and continue to innovate in the same product type? (Buyukozkan and Feyzioglu, 2002) or choose a different product from what we produced in the past? Choosing this decision is very important for the future of the company and the product. Competitive advantage is what makes a customer prefer one brand to another, or a new product to an old product of the same brand (Song and Noh, 2006). The platform is aligned with the company's goals so that a defined advantage can help enhance the brand's product portfolio.

4.2.3 Full and accurate definition of product features

It is important to create a good competitive advantage to define product characteristics (Schmidt, 2005). This definition should be well-suited to engineers, managers and operational staff. One manufacturer said: „If we can't make the new product feature visible on the market, we will have no way to attract customers".

4.3 Strategy Developments

This part of the development emphasizes organizational activities. To this

Table 3. Selected codes for product structure development categories

Main-Components	Sub-Components	Selective codes
Development of product structure in modular platform	Product performance Architecture	The degree of product difference from market competitors Production of homogeneous or heterogeneous products being different Full and accurate definition of product features

Table 4. Selection Codes for Strategy Development Categories

Main-Components	Sub-Components	Selective codes
Strategy Development in Modular Platform	Product idea Product Basket Specializing in contractors	Targeting the market Price contrast with product quality Supplier status and partnership in new product development Continuous improvement Development Financial Risk Capability and consideration for future development

end, one must have sufficient mastery over the organization, and each component must be developed in the same way as a new product. The following 6 selection codes will address this main component (Table 4).

4.3.1 Targeting the market

After segmenting the market, the next step is to select one or more market segments as the target. Target selection should take into account criteria such as cost difference, demand level, estimation of demand growth, number of competitors, culture of consumption, etc. (Millson & Wilemon, 2006).

4.3.2 Price contrast with product quality

We can observe two key elements for the manufacturer to optimise the mix of price and product marketing: to try to reduce prices and increase quality (Postma et al., 2012). It's not simple problem! An interviewed producers said: „One of our products is Roham car. Costs increases due to changes in raw material prices put a lot of pressure on our products. We reduce production costs to maintain our price. This kind of product development is still going on in our company".

4.3.3 Supplier status and partnership in new product development

A manufacturer is only part of the product supply chain (Lam and Chin, 2005). It is advisable for manufacturers to design and develop a new product by using their own platform module to keep current suppliers informed of their future plans. On the other hand, the suppliers also needs to define their future plan according to manufacturers demand. This is a two way interaction.

4.3.4 Continuous improvement

„What comes to your mind as an innovative idea has the potential to be even more fulfilling in the years to come" (Liu et al. 2005). If a company can come up with an innovation, it can benefit from it for years.

4.3.5 Development Financial Risk

The greatest concern for new product design and development using the platform module is the financial risk of investing in the new product (Ozer 2006). Fortunately, scientific advances in economics have made it possible for professionals to determine the reliability of new product design and development.

4.3.6 Capability and consideration for future development

The desire to introduce new technologies in the design and development of new products should be supported by technical capabilities, scientific, technological, financial and human resources. A multi-criteria analysis is needed to identify optimal solutions.

4.4 Organizational Development

Key proponents and energy providers of the new product design and development process should have access to sufficient and effective resources (To et al., 2009). Table 5 summarizes three selection codes extracted from expert opinions.

4.4.1 Continuing Training

The speed of the science and technology development process has forced executives to continually utilize up-to-date human resources and expertise to create a new product design and development using a continuous and sustainable platform module (Lai et al., 2012). The best way to educate and keep experts up to date requires that the training should be continuous and targeted.

4.4.2 Cultivate creativity and create a culture of creativity

Is not always the way to success to go only with the R&D unit to design and develop a new product using a modules platform. Successful organizations strive to foster the spirit and culture of creativity and ideation at all organizational and occupational levels (Postma et al., 2012).

4.4.3 Attracting or allocating sufficient funding for new product design and development

Two common ways to finance product development are:

(1) companies allocate a percentage of the profits from the company's entire activity to product development; or, for each product under the future development plan, a percentage of the profits of the same product be saved for development;

(2) the use of banking facilities.

Obviously, outsourcing through stock sale or investor attraction is not recommended at all.

5. CONCLUSION

Regarding the issues raised in this paper, it can be concluded that the first achievement of this research is the introduction of four main categories of success of new product design and development using platform module in Iranian automotive industry including: (1) Technology development,

Table 5. Selected codes for resource development categories

Main-Components	Sub-Components	Selective codes
Organizational Development in Modular Platform	Organization with product design and development process capability	Continuing Training Cultivate creativity and create a culture of creativity Absorb with sufficient funds to design and develop a new product

(2) Product structure development, (3) Strategy development, and (4) Organizational development. Production structure development is the basic step in the process of new product design and development using a platform module. This can drive technology development and both will lead to strategy development.

In the meantime, organizational development as the core of the new product design and development process will affect all three other components.

Therefore, in order to develop a new product, the structure of the product must first be addressed. To this end, the uniqueness of the new product, the competitive advantage, the correct positioning of the product, and the capability for future development must be taken into account.

These can also help build effective prototypes in the context of technology development and make it easier to choose new design and production methods. What boosts the confidence in this approach are strategic development plans that include: market segmentation and identifying new potential markets, adjusting marketing mix to suit market conditions, and momentary market dynamics to reduce financial risk and look to the future. The design and development a new product using the platform module not be successful only by relying on one or two sub-components. The complexity of the identified components suggests that the development process is part of the companies' medium and long-term plans.

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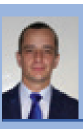
SIMULATION AND COMPARATIVE ANALYSIS OF POLLUTANT EMISSIONS BEFORE AND AFTER PID CONTROL OF ENGINE FUNCTIONING

SIMULAREA ȘI COMPARAREA CANTITĂȚII DE EMISII POLUANTE DUPĂ OPTIMIZAREA PID A FUNCȚIONĂRII MOTORULUI UNUI AUTOTURISM AUDI A6

REZUMAT:
Lucrarea de față prezintă unele aspecte ale studiilor întreprinse pentru optimizarea funcționării unui motor cu aprindere prin scânteie în vederea reducerii consumului de combustibil și a emisiilor poluante. Optimizarea teoretică a funcționării motorului autoturismului Audi A6 s-a realizat cu ajutorul unui program dezvoltat în limbajul de programare Matlab20a în vederea reducerii consumului de combustibil. Ulterior, pe baza datelor optimizate, s-a simulat cantitatea de emisii poluante cu ajutorul altui software. Toate caracteristicile funcționale, geometrice și de performanță ale autoturismului au fost luate în considerare pentru realizarea unei simulări fidele. În același timp, datele simulate au fost salvate în diferite fișiere, iar rezultatele sunt prezentate cu ajutorul graficelor realizate tot în limbajul de programare Matlab20a.

Key-Words: *pollutant emissions, fuel consumption, PID optimization, software simulation.*



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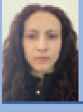

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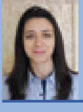

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NOMENCLATURE
PID – Proportional Integrative Derivative

1. INTRODUCTION

Nowadays, environmental pollution has become a serious topic, which is constantly monitored by specialists. According to statistics, in 2015 there have been approximately 73 millions motor vehicles in daily use on public roads. It is estimated a number of 2 billion vehicles by 2035, which will determine an increased atmospheric and environmental pollution [1][6].

Current concern of automotive engineers is to reduce fuel consumption with impact on preserving oil supplies and also to decrease the amount of pollutant emissions which are responsible for global warming. Reduced fuel consumption implies more fuel efficient engines. Also, the smaller the quantity of burned fuel, the lower the amount of exhaust gas resulted from engine functioning [5].

Within this article, it is intended to determine exhaust gas quantity and it's constituents after applying a PID controller for optimal results. Initial data used for subsequent optimization process have been obtained during tests conducted on an Audi A6 3.0 TFSI Quattro motor vehicle. The testing procedure consisted in a relatively aggressive driving (or dynamic driving) of the vehicle, on a crowded highway. Specific parameters were acquired and collected with the use of a dedicated diagnostic tester for VAG, Ross-Tech VCDS group [4].

The Audi A6 vehicle is equipped with a 2995 cc V6 engine, maximum engine power is 245 kW, and maximum torque according to the manufacturer is 440 Nm. Also, the producer indicates a fuel consumption of 9.8 l/100 km for urban driving, 6 l/100 km for extra-urban and 7.4 l/100 km for combined driving. Regarding vehicle mass and dimensions, the parameters are the following: 2360 kg mass, 4932 mm total length, 1874 mm width and 1455 mm height.

2. OPTIMIZATION THROUGH PID CONTROLLER

The analysed motor vehicle comes equipped with a factory three-way catalytic converter, which transforms the pollutant emissions in safe constituents for the environment. Present paper was not focused on changing catalytic converter parameters, but on reaching lower fuel consumptions and decreased amount of toxic gases by applying PID controller (proportional-integral-derivative) on speed variation obtained experimentally. This control algorithm is specific to automated system theory and combines the advantages and disadvantages of the three basic coefficients used to obtain an optimal result. Some of the advantages worth mentioning are: rapid response, zero state error and high order overload.

The output size, used to actuate PID controller, noted „c", is defined by the following mathematical expression [2]:

$$c = k_p\left(e + \frac{1}{T_i}\int_0^t e\,dt + T_d\frac{de}{dt}\right) + c_0 \qquad (1)$$

where kp – proportional factor and it is equal to $k_p = \frac{100}{BP}$, BP represents proportionality band width, T_i – integral time constant, T_d – derivative time constant, c_o – control in absence of deviation, e – relative error.

In a comprehensive understanding, fuel economy means to reduce fuel consumption. Nowadays, it is aimed to obtain a higher fuel saving, which has a negative effect on engine dynamics, meaning that it is not possible to obtain an increase of all specific parameters. For further understanding, fuel saving can be indicated by an average fuel consumption expressed in liters per 100 kilometers (l/100 km) and engine dynamics can be evaluated by average speed, average acceleration etc. Due to the complexity of analysis of the two phenomena, present paper is focus only on fuel saving aspects.

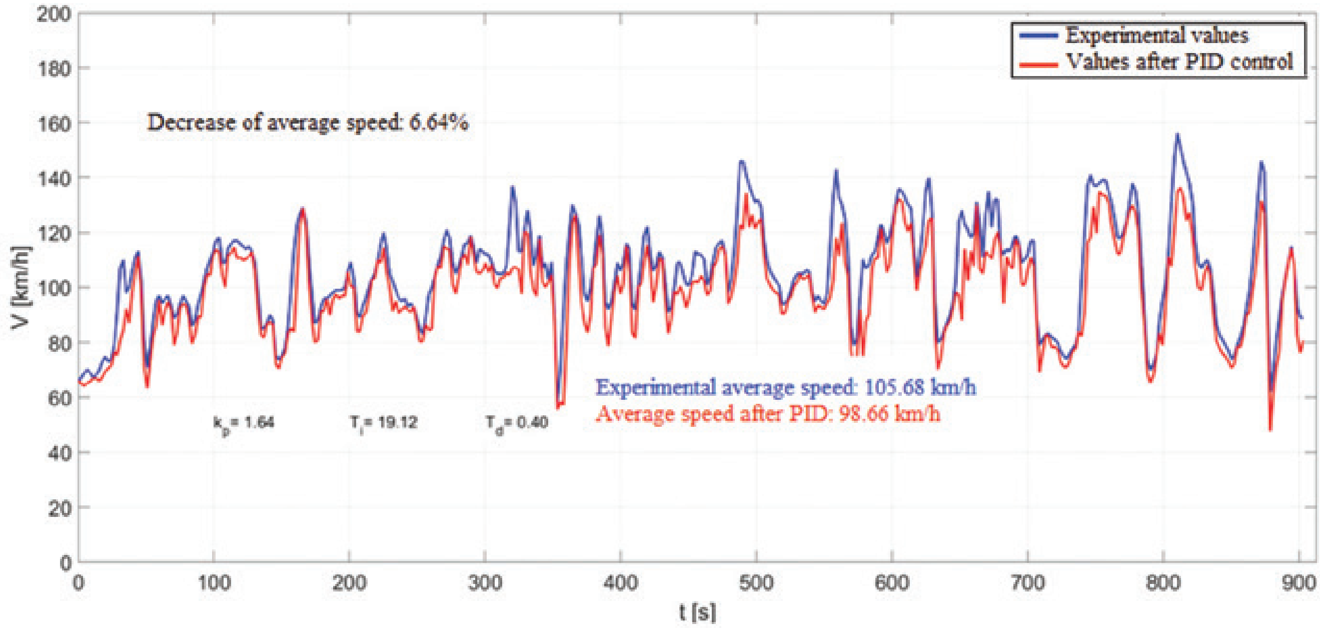

Fig. 1. Vehicle speed before and after applying a PID controller

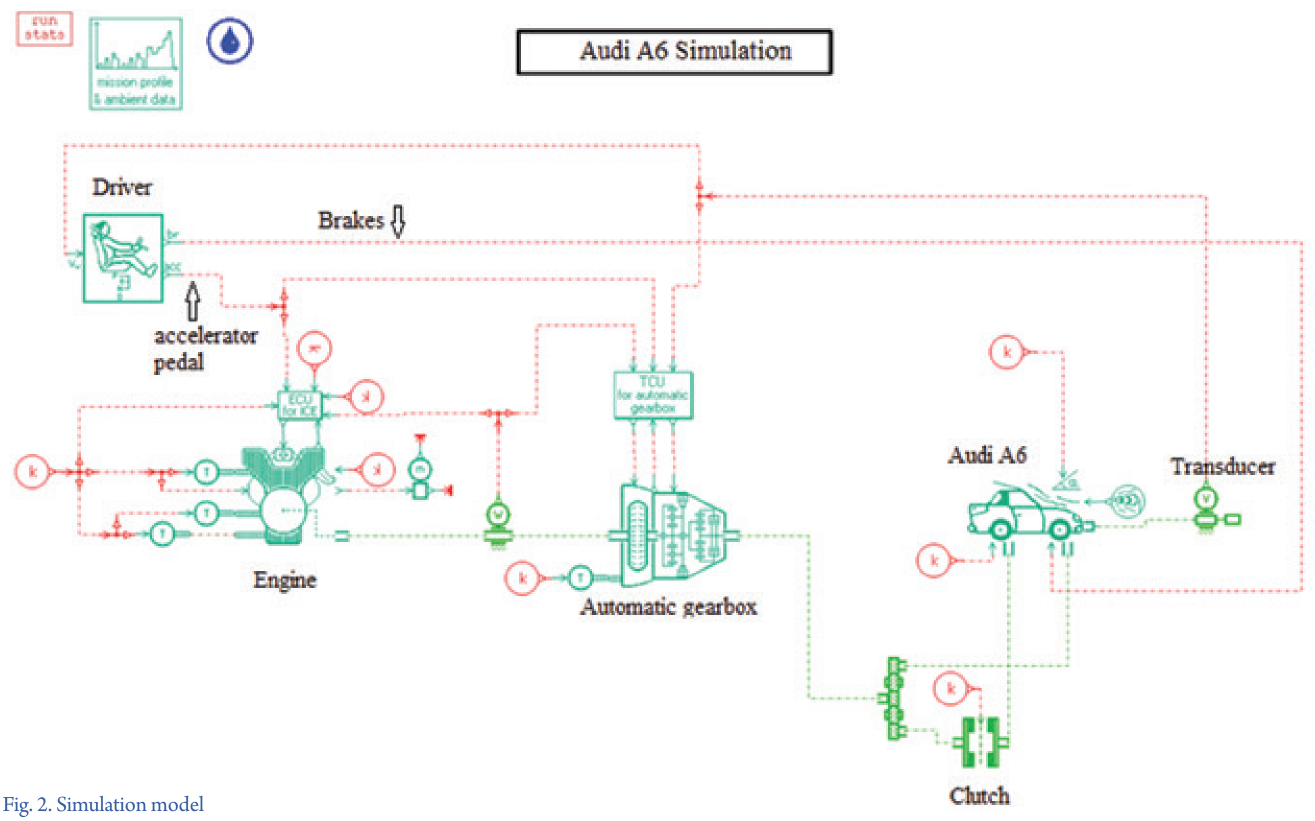

Fig. 2. Simulation model

Therefore, when applying a PID controller on vehicle speed variation, it was obtained a decrease in average speed. The results are presented in figure 1. As it can be observed from the graph, the average speed obtained experimentally was 105.68 km/h, and after applying the PID controller, the average speed decreased to 98.66 km/h. Hence, a comparative analysis of the two values indicate a decrease of average speed by 6.64%. Yet again, on the graph there are also presented all three variables of transfer function for PID controller: $k_p = 1.64$, $T_i = 19.12$ and $T_d = 0.40$. The values of these constants have been determined empirically, by taking into account dynamic characteristics of the analysed vehicle.

3. SOFTWARE SIMULATION

Based on automobile characteristics and speed values (initial and after PID controller) there have been performed two parallel simulations in a dedicated and advanced software program. It was developed a model able to simulate the vehicle while driving in certain conditions, similar to those existing at the time of experimental tests. The model used for simulation

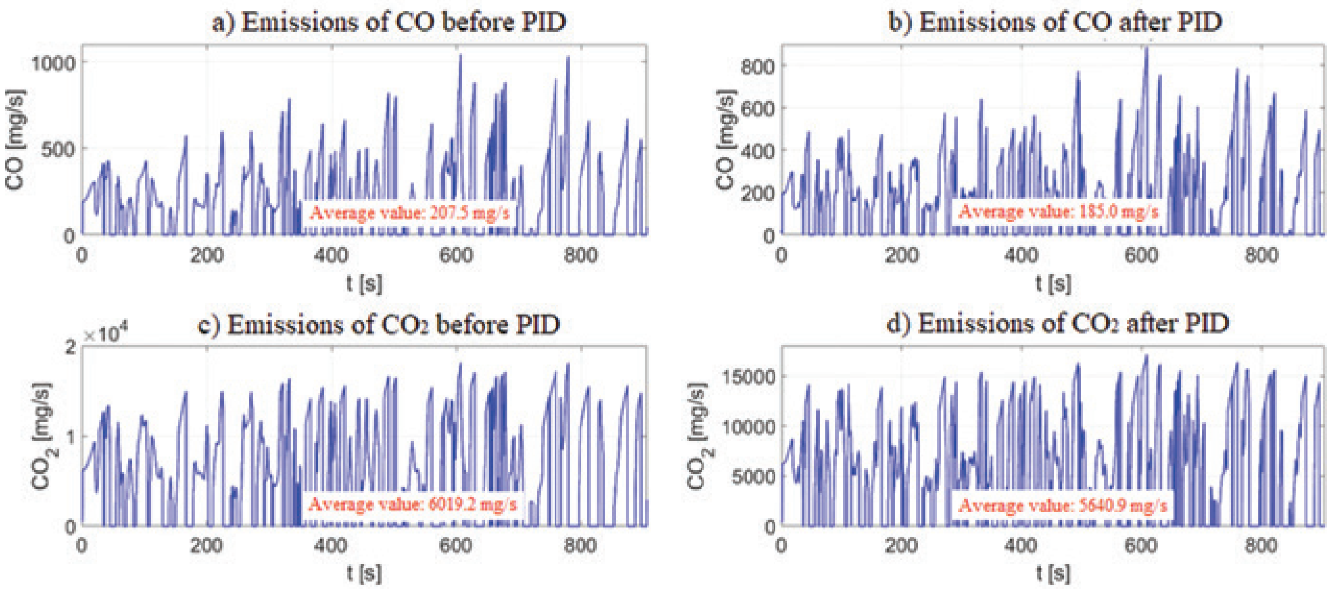

Fig. 3. Comparative emissions of CO and CO_2 resulted from simulation, Audi A6

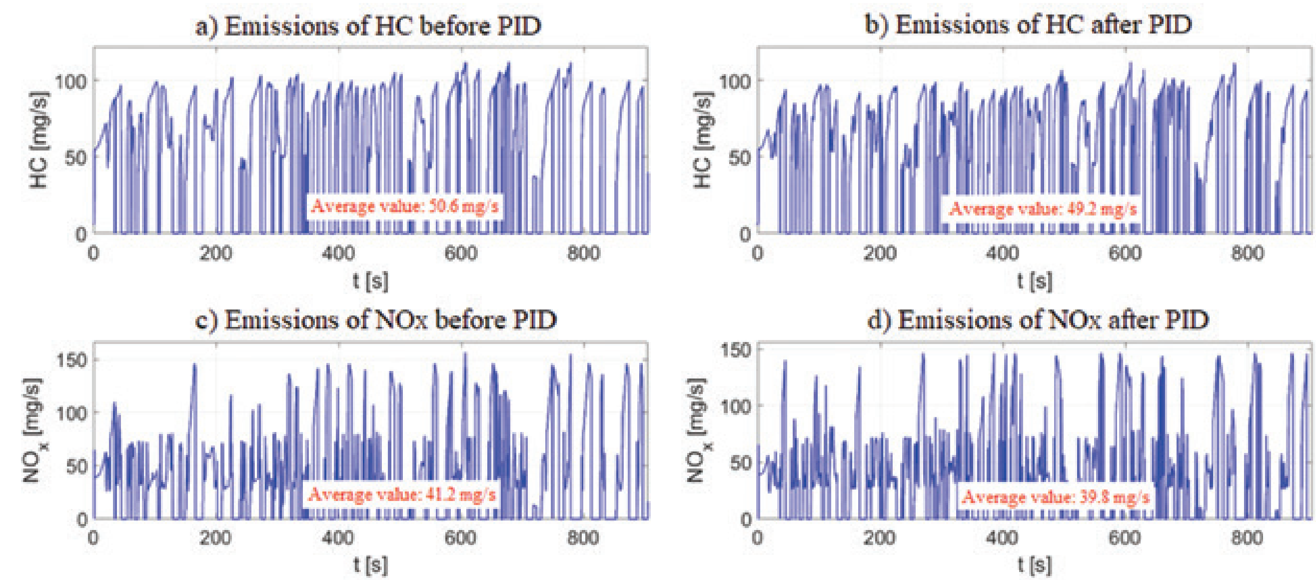

Fig. 4. Comparative emissions of hydrocarbures and nitrogen oxides resulted from simulation, Audi A6

is depicted in figure 2. It must be mentioned that some parameters were not adjusted according to reality, namely wind speed, slope variation of the road and accurate indication of when the gear shifting occurred due to the automated gearbox.

At the same time, the simulation is very strictly controlled because it takes into account multiple physical phenomena that are characteristic to the driving tests performed on a highway. For example, there were taken into account parameters such as: all resistive forces, contact forces between the tire and the rolling track, friction forces characteristic to mechanical connection of the four-wheel drive, thermodynamic processes which occur within the spark-ignition motor vehicle etc. [3].

From the model presented in figure 2, it can be observed that the software uses different colors depending on the constituents. Therefore, red is used in case of electronic components and circuits, turquoise is used to simulate different predefined mechanical assemblies and subassemblies specific to automotive engineering (e.g. engine, automatic gearbox, motor vehicle etc.) and green is used to indicate individual mechanical parts (e.g. transducers).

4. SIMULATION RESULTS

Simulation results regarding exhaust gases are presented in the following figures. There can be depicted graphs of different pollutant emissions, before and after applying a PID controller.

In figures 3a and 3b there are presented instantaneous emissions of carbon monoxide, resulted from simulation, before and after the optimization process. The entire simulation lasted 905 seconds. As it can be observed from the graphs, in case of optimized engine, the quantity of carbon

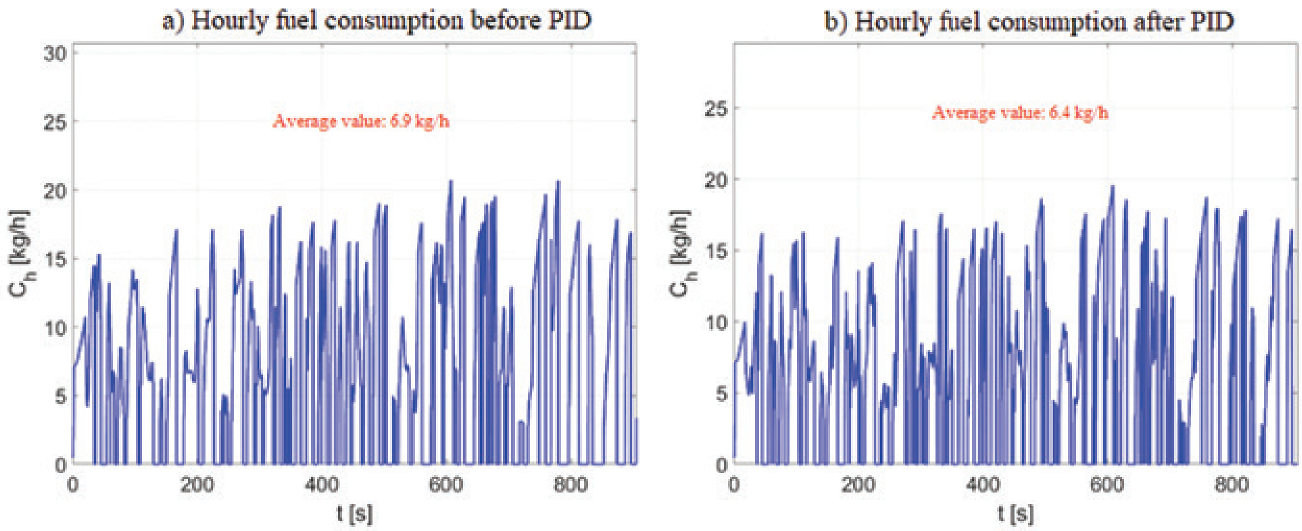

Fig. 5. Hourly fuel consumption, before and after PID control, Audi A6

monoxide measured at the exhaust pipe is with approximately 11% lower that without applying a PID controller (207.5 mg/s before PID control and 185.0 mg/s after the optimization process).

Yet again, in figures 3c and 3d, there are presented carbon dioxide quantities resulted from simulation with the Audi A6 automobile, running on the highway, before and after applying a PID controller. According to the manufacturer, for EURO 6 engines, the NEDC (New European Driving Cycle) test indicates 172 g/km of carbon dioxide generated while driving on highway, which is similar to the value resulted from simulation, namely 217.88 g/km [7].

As it can be observed from the bottom left graph, the initial simulation of the motor vehicle indicated an average value of 6.019 g/s carbon dioxide, while the bottom right graph shows that the average value of CO2 emissions is 5.640 g/s. Hence, due to the optimization process of engine functioning, it was obtained a decrease of 6.7 % in case of CO2 emissions.

In figure 4 there are presented emissions of hydrocarbures and nitrogen oxides, during the two parallel simulation conditions. In case of the upper graphs, it can be observed that the use of a PID controller determined a decrease by 2.8% of hydrocarbures resulted from engine functioning (50.6 mg/s during initial simulation as opposed to 49.2 mg/s, after applying a PID controller).

From the lower graphs of figure 4, a comparative analysis can be made regarding emissions of nitrogen oxides resulted during simulation. As it can be observed, the optimization process applied on engine resulted in a decrease of 3.4% regarding emissions of NOx (the average value of NOx emissions before applying PID controller was 41.2 mg/s and after the optimization process it was recorded an average value of 39.8 mg/s). Simulation time lasted 905 seconds.

In addition to the analysis focused on reducing pollutant emissions by applying a PID controller, follow-up there are also presented several results regarding the effects on engine fuel efficiency, mainly average hourly fuel mass consumption. In figure 5 there are presented comparative results of hourly fuel consumption, before and after applying proportional-integral-derivative control.

By analysing the two graphs, it can be observed a decrease of average fuel consumption, from 6.9 kg/h to 6.4 kg/h. The difference of 0.5 kg/h between the two situations, can also be expressed in average volumetric fuel consumption, obtaining a value of 0.37 litre/h.

5. CONCLUSION

The paper presented a comparative analysis regarding pollutant emissions and engine efficiency, based on experimental results obtained while performing tests with an EURO 6 automobile. With the use of parameters acquired during tests, there were performed comparative simulations of engine functioning, before and after applying a PID controller. Thereby, simulation error can be excluded.

On the other hand, it was also observed a drawback while using simulation, namely that the model show zero fuel consumption and exhaust gases during braking periods, which is not correct.

Regarding the amount of pollutant emissions and engine efficiency, all figures argued that the use of a proportional-integral-derivative controller to actuate the accelerator pedal, has the advantage of improving fuel economy (in this case, by approximately 1.32%, from 2.32 litres to 2.29 litres) and reducing the amount of exhaust gases.

Still, it has to be mentioned that a decrease of fuel consumption determines also a decrease of vehicle speed, due to the fact that fuel saving and engine dynamics are divergent one from the other. As a result, it was observed a decrease of average speed by 6.64% after the optimization process.

Also, on average, pollutant emissions recorded after the optimization process were by approximately 2.5% lower than before applying PID controller.

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ASPECTS REGARDING EXPERIMENTAL ANALYSIS OF PHYSICAL PROPERTIES OF A DIESEL ENGINE FUELS

UNELE ASPECTE PRIVIND ANALIZA EXPERIMENTALĂ A PROPRIETĂȚILOR FIZICE ALE COMBUSTIBILILOR MOTOARELOR DIESEL

REZUMAT:
În această lucrare sunt prezentate unele aspecte ale cercetărilor experimentale efectuate privind alimentarea motoarelor diesel cu diverse sorturi de combustibili. Au fost studiate elemente ce descriu caracteristicile fizice ale amestecurilor de motorina cu bio-combustibili în proporții de 20%, 50%, 75% și 100%. Analiza comparativă a avut în vedere proprietățile amestecurile de combustibili menționați și ai motorinei, precum și rezultatele obținute prin efectuarea de teste de lungă durată pe bancurile de probe.

Key-Words: *Diesel fuel, compression ignition engine, density, viscosity, flash point, cloud point, energy performance, engine testing cell*

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1. INTRODUCTION

Considering the fact that energy requirements are on the rise and that fossil fuel supplies are exhausted, anthropogenic emissions of greenhouse gases (ges), being the main cause of climate change and the ecological system talk about the need to research new ways of producing energy from sources and alternatives to replace these classic fuels [1].

The issue of alternative energy sources is not a novelty, because their use was widely applied in the Republic. of Moldova due to the requirements of European Union fact that confirms the ONU Convention for Climate Change (1992) and the Kyoto Protocol (1997), ratified by the Republic of Moldova in 2003, but also the need to reduce sources of environmental pollution, in general, of residues resulting from the burn of fuel, derived from fossil hydrocarbons (petrol, natural gas, diesel, etc.). For the Republic of Moldova the most accessible sources of alternative energy to fossil fuels are plants and partly animal fats [2][3][4].

Pure vegetable oil - is the oil produced from oilseeds by pressing, extraction, crude or refined, but not chemically modified, in case if its use is compatible with a type of engine and with the corresponding emissions requirements. Due to lower exhaust emissions, vegetable oils used as fuel are gaining more and more popularity. From an economic point of view, it has been found that the optimal variant is the use in Internal Combustion Engine (ICE) of monoesters obtained from vegetable oils, in this case from rapeseed oil. Rapeseed oil can reduce carbon dioxide emissions by 70% compared to petroleum-based fuel, thus reducing greenhouse gases, which contribute to global warming.

Biofuel is composed of alkyl esters obtained by transesterification of vegetable oils or animal fats. This biofuel is biodegradable, it is not toxic and generates fewer noxious poisons from its burning: such as NO_2, SO_2 than petrol products when it is burnt. In the Republic of Moldova, as in other European countries, the use of biofuels as an alternative to diesel fuel will be achieved in stages from the following considerations: the low volume of rapeseed oil production in the republic (only 3 thousand tons of oil was produced in 2007 from rapeseed by the Moldavian-German company „Bio-Raps-Compania"); lack of biofuel production facilities; dependence on biofuel exporting countries.

Therefore, the first stage of the use of biofuel according to the requirements of art. 6 of the Renewable Energy Law [4] in the year 2010 the volume of biodiesel and diesel fuel will account for 5% of the volume of diesel sold, and in 2020 this biodiesel-diesel mixture will be -20%.

The research's aim was to study the physical characteristics of the mixture of biofuels and diesel.

2. MATERIAL AND METHOD

The tests were carried out in the Internal Combustion Engines Testing Laboratories and the Physical and Chemical Properties and Exploration of Petroleum Products Research, the Faculty of Agrarian Engineering and Auto Transport, at the Department of Transportation Engineering and Tractors, several researches have been carried out on:

- the possibilities of using vegetable oils (rapeseed, sunflower, soybean), metyl-esters, mixtures and waste oils as well as diesel fuel;
- the influence of these fuels on:
- engine performance (engine torque, engine power, fuel hour consumption, specific fuel consumption);
- pollutant emissions of the engine;
- engine durability;
- the influence of some factors on the properties of biofuels;
- biodiesel addition.

In order to evaluate the possibility of using vegetable oils and their derivatives as diesel substitutes,, were taken into consideration the following main characteristics: viscosity, density, calorific value, cold behavior, stability during storage.

The fuel viscosity influences the engine power and spraying it into the combustion chamber. The calorific power allows to provide the maximum power that can be developed by an engine for a given injection pump flow rate. Comparative analysis on chemical elements shows the advantage of using biofuel from rapeseed oil to classic fuel.

Biofuels are slightly poorer than diesel in terms of carbon content

Table 1. Quality characteristics of the studied fuels

Task	Composition	Kinematic viscosity at 20oC [cSt]	Absolute density [g/cm³]	Point of inflammation [°C]	Point of disorder [°C]	Power calorific lower [MJ/kg]
№ 1	Diesel fuel	4,92 ± 0,24	0,834 ± 0,04	65 ± 3,8	-15 ± 0,73	43,89
№ 2	Diesel fuel 80% Biofuel 20%	6,71 ± 0,34	0,846 ± 0,04	76 ± 4,2	-12 ± 0,61	43,24*
№ 3	Diesel fuel 50% Biofuel 50%	9,12 ± 0,47	0,862 ± 0,04	85 ± 5,0	-10 ± 0,47	42,28*
№ 4	Diesel fuel 25% Biofuel 75%	11,60 ± 0,57	0,880 ± 0,05	>100 ± 6,0	-8 ± 0,44	41,48*
№ 5	Pure biofuel	13,01 ± 0,64 5,20 ± 0,26**	0,895 ± 0,05	>120 ± 7,0	-2 ± 0,01	40,69*
№ 6	Rapeseed oil	75,58 ± 3,78	0,915 ± 0,05	> 120 ± 7,5	-2 ± 0,02	40,69

Note:
* Values are presented after calculation.
** Kinematic viscosity at 40oC, cSt according SM STB 1657:2009 (EN 14214:2003).

(-8,98 %) and hydrogen content (0,79 %). It is noted the fact that, the oxygen is present in the biofuel structure (approx.10%) – which favors the combustion process in the engine. It also notes the total lack of sulfur - which leads to the reduction of chemical pollution (does not contribute to SO_2 emissions).

Comparing the physical characteristics of fuel from vegetable oil to classical fuel (diesel), the qualities of this new fuel are once again highlighted.

3. RESULTS AND DISCUSSIONS

The physical properties are experimentally analyzed of various biofuel and diesel blends (density, viscosity, flash point, disruptive point, thermal analysis) being made then a comparative analysis with different biofuel standards.

The fuel mixture was prepared in gravimetric proportion from a single reference diesel and biofuel batch in the following ratio: diesel / biofuel 80/20 (B20); 50/50 (B50); 25/75 (B75), pure biofuel 0/100 (B100).

The quality characteristics of the fuels studied are presented in Table 1.

For the evaluation of the possibility of using the diesel fuel - biofuel as an alternative fuel the following physical and chemical properties must be considered: kinematic viscosity at 20°C, density, point of inflammation, crystallization point, distillation range, lower calorific value, storage stability.

Absolute density, kinematic viscosity and vaporization temperature become important characteristics for achieving the combustion process of the fuel mixture.

The absolute density or specific weight for biofuel is 7.3% higher than for diesel.

The kinematic viscosity influences the engine power and fuel spraying into the combustion chamber.

The experimental data presented demonstrates that, with the increase of biofuel added to diesel fuel, the viscosity of the mixture increases compared to diesel: for the mixture B20 with 36,4%; the mixture B50 of 1,85 times and the B75 of 2,35 times [5].

Fuel mixture B20 has the kinematic viscosity of 6,71 mm2/s very close to the limiting summer viscosity range – 3 … 6 mm²/s (after STAS 305-82) which allows to use this blend of fuel for Diesel engine's operation without constructive changes of the engine. This fuel blend B20 was used in engine D-241 tests and to the in-service tests of tractors MTZ-80 equipped with these engines. Figure 1 shows some D-241 engine components after 100 hours of operation with alternative fuels.

The B20 fuel mixture will ensure a light start of the diesel engine, even in the cold weather of the year, will provide a good quality of self-ignition and combustion of the fuel blend.

The change in the kinematic viscosity of the biofuel blend in dependence on the biofuel weight in this mixture is shown in Figure 2.

The ignition and the B20 fuel combustion process will essentially depend on actual air mixing and combustion initiation temperature, and this blend of diesel fuel - biofuel (B20) may be recommended to be used especially during the warm year.

The existence of a dual fuel system: diesel and biofuel, which becomes necessary in cold periods, when due to the high viscosity of the biofuel, the fuel injection is inadequate, creating problems, especially when starting the engine. Another factor is the type of biofuel feedstock used on the engine.

Inflammation temperatures for the studied samples change significantly (within the limits of 75-120°C) which is an important fuel safety indicator. The biofuel-gas mixture is a less dangerous fuel compared to diesel fuel, namely: lower ignition and explosion hazards during transport or during storage.

Calorific heat is an important fuel feature that determines the maximum engine power at a correct injection pump setting. For vegetable oils, the

Fig.1 D-241 engine components after 100 hours of operation with alternative fuels

average calorific value is about 40,688 MJ/kg, compared with 43,890 MJ/kg for diesel fuel [6]. For the B20 fuel blend, calorific value (after calculation) will be 42,640 MJ/kg with only 1.48% lower than diesel fuel, with 7.3% less for rapeseed oil. The non-essential reduction in the calorific value of the B20 fuel will not contribute significantly to lowering the engine's energy performance (power, torque, fuel consumption).

4. CONCLUSIONS

The study on the use of biofuel allows the following conclusions:

• The B20 fuel mixture has a calorific value (after calculation) of 42,640 MJ/kg with only 1.48% less than diesel, which will not contribute significantly to the performance decrease energy of the engine;

• The fuel blend B20 (diesel + 20% biofuel) has been shown to be the most optimal blend in terms of the diesel engine's energy performance compared to its diesel fuel efficiency;

• Specific fuel consumption is changing insignificantly, determined not so much by hourly consumption, how to reduce engine power when running on blends of fuels (diesel fuel - biofuel);

• Biofuel and biofuel diesel blends ensure a reduction in CO, CO_2 and C_nH_m emissions in exhaust gases up to engine load of 75% effective power;

• Attempts at the stand demonstrate the fact, that the engine fueled with diesel fuel and 20% biofuel can work impeccably up to the limit of wear, which is more than satisfactory;

• Taking into account the general tendency in Europe as well as the natural climatic conditions of the geographical position of the Republic of Moldova, as well as the socio-economic requirements of the Republic, vegetable oils and vegetable esters have the most promising economic development prospects in the direction of biofuel production ;

• The use of biofuel in the Internal Combustion Engine (ICE) contributes to the reduction of pollutant emissions in the exhaust gases, which is an important thing for our century.

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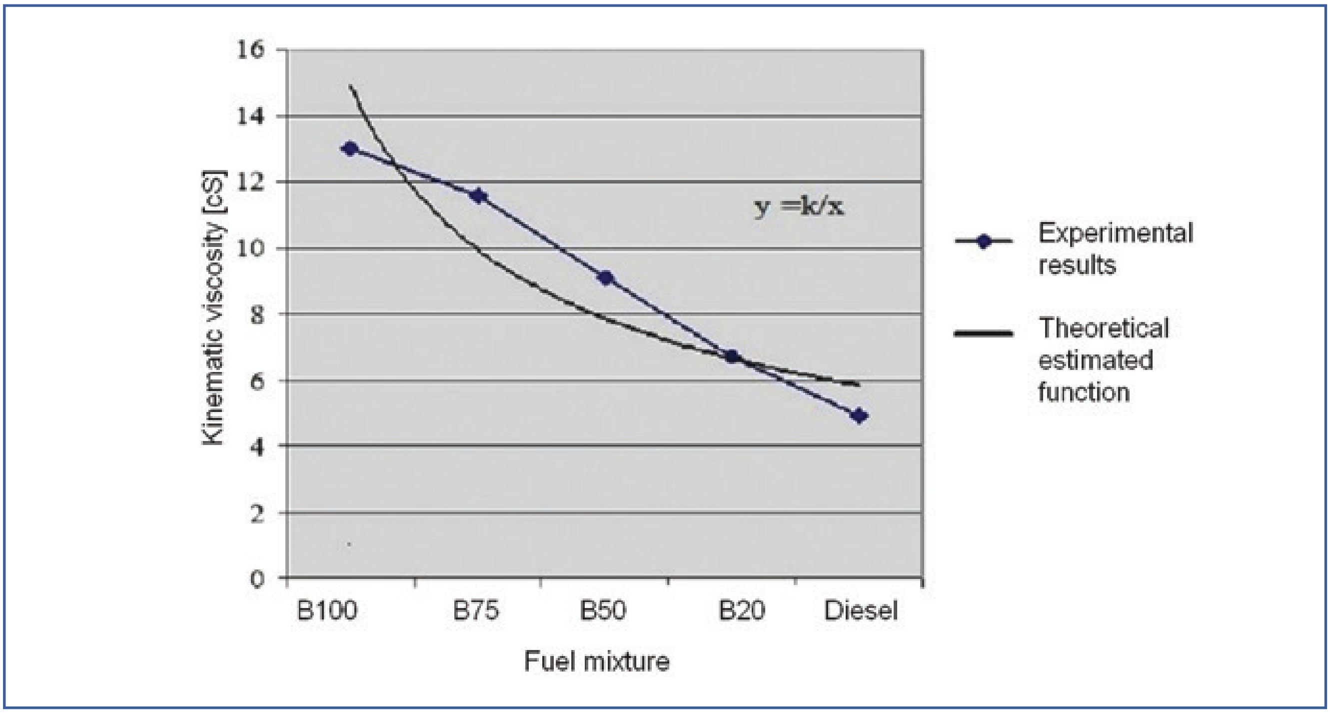

Fig. 2 The variation of the kinematic viscosity of the studied fuels

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