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UNIVERSITY OF KRAGUJEVAC, FACULTY OF ENGINEERING

SERBIAN SOCIETY OF AUTOMOTIVE ENGINEERS

M V M **M**obility **V**ehicle **M**echanics

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A PROPOSED MODEL FOR OPTIMIZING THE DRAWBAR PULL FOR OFF-ROAD VEHICLES

Mohamed Khalil, Mohamed Ali Emam[1]

UDC:629.1.05

ABSTRACT: The whole world is looking for the energy that it considers the driving forces for any development in the world. On the other hand, it resorted to energy inherent in petroleum and the world felt that this energy will wind up. For this reason, the developed countries directed their research to reduce the fuel consumption of the vehicles in addition to using the renewable energy. This paper proposes a new expert system for optimizing the tyre drawbar pull, especially for off road vehicles. The system depends on measuring the wheel slip to control on the tyre inflation pressure by using the self - inflation pressure system to maximize the drawbar pull for the off road vehicles and accordingly to reduce the fuel consumption.

KEY WORDS: terra-mechanics, off road vehicles, drawbar pull, slip, tyre inflation pressure, self-inflation pressure

PREDLOG MODELA ZA OPTIMIZALNU VUČNU SILU VOZILA ZA VANPUTNE USLOVE

REZIME: Ceo svet je u potrazi za energijom koju smatraju pokretačkom snagom za bilo koji razvoj u svetu. Sa druge strane, energija sadržana u nafti je inherentna i svet smatra da će ta energija nestati. Iz tog razloga, razvijene zemlje usmeravaju svoja istraživanja da smanje potrošnju goriva vozila pored korišćenja obnovljivih izvora energije. Ovaj rad predlaže novi ekspertni sistem za optimizaciju sile vuče na točku, posebno kod vozila za vanputne uslove. Sistem na osnovu izmerenog proklizavanja točka upravlja pritiskom u pneumaticima korišćenjem sistema za regulaciju pritiska kako bi se vučna sila povećala i shodno tome smanjila potrošnja goriva.

KLJUČNE REČI: mehanika tla, vozila za vanputne uslove, vučna sila, klizanje, pritisak u pneumaticima, samo-regulišući pritisak

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A PROPOSED MODEL FOR OPTIMIZING THE DRAWBAR PULL FOR OFF-ROAD VEHICLES

Mohamed Khalil [1], Mohamed Ali Emam[2]

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1. INTRODUCTION

The study of the terra-mechanics is the interaction of tyres on various deformable terrains and it is not an easy task. The ideal vehicle has to provide excellent off-road capability with low fuel consumption, offer a high customizability for each specific mission and, last but not least, it has to be easy to operate. To meet these demands must be doing many of the research for the study of factors affecting these demands. The fuel economy has always been an important consideration for truck owners and fuel expenditure is one of the leading operating costs in the trucking industry.

Today, fuel economy is even more important with record high diesel prices. Many researchers are currently developing various technologies for improving fuel economy, such as; vehicle body aerodynamics, route management, engine and drive system and running gear design, and proper maintenance. Figure 1 represents the main factors that affect fuel economy during operating the vehicles in the real world.

One of the factors that have a considerable influence on vehicle fuel economy is the tyre inflation pressure as shown in the Figure 1. Therefore, this study focuses on the relationships between tyre slip, inflation pressure, and traction that when optimized the off-road vehicles` fuel consumption would be effectively reduced [1]. From the Figure 1, it could be said that the tyre inflation pressure is the one of the parameters that has affected the fuel economy during driving the vehicle and it can be used in a control system. This parameter affects the tyre slip, rolling resistance, drawbar pull, and traction force and fuel economy.

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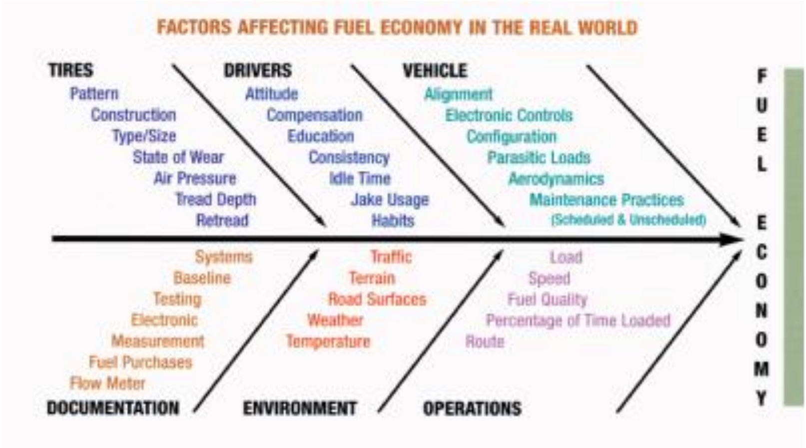

Figure 1 Factors affecting fuel economy in the real world [2] and [3]

The interaction between the wheel and the medium on which a vehicle operates is the main factor to find the optimum performance from an off-road vehicle, as seen in Figure 2. The problem of wheel-soil interaction may seem antiqued in this technological advanced age of space exploration, computers, microelectronics and robotics. It is, nevertheless, a complex problem, at least from an analytical viewpoint, for the characteristics of wheel-soil interaction is influenced by a large number of factors [4].

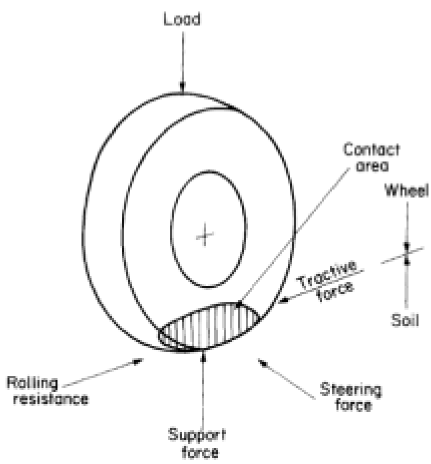

Figure 2 Forces acting on a rolling tyre in soil [4]

Now most of the new military tactical vehicles produced in the United States are equipped with Central Tyre Inflation System (CTIS) where this system is used to adjust the tire pressure to the optimum footprint on any terrain. In addition, the CTIS reduces downtimes associated with tire malfunctions, such as minor punctures, leaks, or immobilization in muddy terrain. Therefore, the most of wheeled armoured vehicles are equipped with a CTIS Tyres for help during emergency conditions [5]. The CTIS allows the tyres to dynamically change to lower inflation pressures to accommodate speed in rough terrain. The reduced pressure allows the tyre to be more compliant, thereby maintaining better ground contact, as well as giving the operator a more comfortable ride. In agriculture, CTIS has been a subject of discussion for some time, as mentioned by Hassan [6-7].

Forrest et al [8] stated that some of the enabling factors for central tyre inflation were advances in tyre technology. Early research using radial tyres consistently showed an increase in tractive performance. If the inflation pressure was reduced, the footprint of the tyre became larger and distributed the load over a larger area, helping to reduce the motion resistance in soft soils. Also, if the inflation pressure was reduced, the stiffness of the tyres was reduced. The softer tyres maintained better ride quality by flexing to accommodate for unevenness in the terrain. The 50% reduction in minimum inflation pressure given by the new inflation tables for radial ply tyres increased the vehicle performance when using CTIS, making the economic aspects of central tyre inflation even more appealing.

Schlechter [9] represented briefly the influence of tyre pressure reduction on the mobility of wheeled vehicles on the basis of measurement and calculation results. Significant characteristics and the differences of various central tyre inflation systems installed in series production vehicles and prototypes are demonstrated. Deflation and inflation times of regulation devices serve as performance characteristics for a systematic comparison. Reduction of the tyre pressure helps to increase the transferable traction force, due to the enlargement of the tyre tread area, an enlargement of the effective tyre diameter and thus a reduction of rolling resistance. A tyre pressure reduction from 3.5 bar to 2.0 bar resulted almost in a duplication of the traction force. A tyre pressure of 4.3 bar may possibly permit a vehicle to travel only 65 % of a selected and measured terrain. If the tyre pressure is reduced to 1.3 bar the same vehicle may travel approximately a 90% of the same terrain under the same marginal conditions, as shown in Figure 3. The Ref. [9] supports our idea in this paper where it shows the effect of the tyre pressure on the traction force, which affects the vehicle speed and draw bar pull in the end.

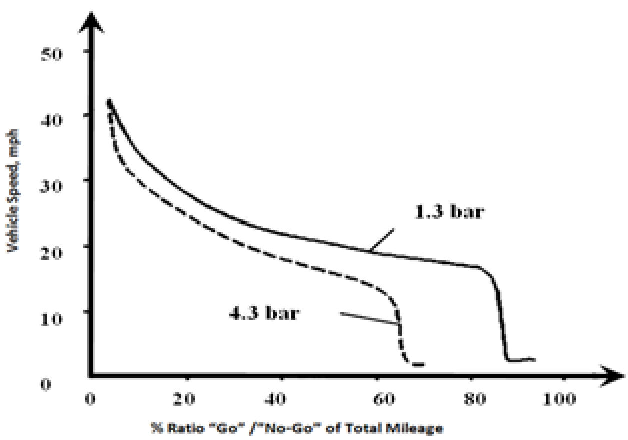

Figure 3 Effect of reduced tyre inflation pressure on the ratio of "Go /No-Go" function of vehicle speed [9]

2. MATERIALS AND METHODS

In this section describe the influence tyre inflation pressure on the contact area; also define the traction efficiency, and found the relationships between tyre-soil interactions.

2.1 Effect of the tyre inflation pressure on the contact area

The tyre dimensions and ground pressures can be changed by controlling the inflation pressure as shown in Fig. 4. Internal air pressure in the tyre directly contributes to the tyre stiffness and controls the contact area and both of them influence the traction capability of the tyre. In general, for better traction on soft loose soil, a decrease in the inflation pressure results in an improvement of normal and tangential interfacial stresses and accordingly in the traction performance of the tyre [11].

	40PSI	35PSI 2.41 bar	30PSI 2.07 bar	25PSI 1.72 bar	20PSI 1.38 bar	15PSI 1.03 bar
Tread length (cm)	19	21 (+2cm)	23 (+4cm)	25 (+6cm)	29 (+10cm)	33 (+14cm)
Tread width (cm)	23.5	23.5	23.5	23.5	23.5	23.5
Tread area (cm)	446.5	493.5 (+47)	540.5 (+94)	587.5 (+141)	681.5 (+235)	775.5 (+329)
% of tread area increase on ground as tyre pressure decreases	-	+10.5%	+21.1%	+31.6%	+52.6%	+73.7%
Pressure tread places on ground (kg/cm)	1.254	1.135 (-0.199)	1.036 (-0.218)	0.953 (-0.301)	0.822 (-0.432)	0.722 (0.532)
% decrease of ground pressure as tyre pressure decreases	-	-9.5%	-17.4%	-24.0%	-34.4%	-42.4%

Figure 4 Effect of inflation pressure on the dimensions and ground pressure [10]

Figure 5 shows contour a set of maps of pressure distribution under 11.0-38 smooth tyre on firm sand at three inflation pressures 0.97, 0.69 and 0.41 bar [12].

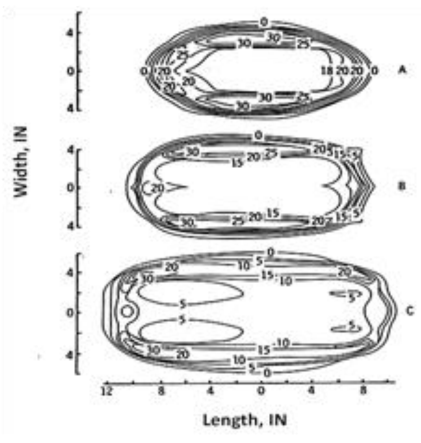

Figure 5 Contour maps of pressure distribution under a 11.0-38 smooth tyre on firm sand at different inflation pressures 0.97, 0.69 and 0.41 bar, [12]

2.2 Load Capacity

The vertical load carrying capability of off-road tyres is mainly determined on the basis of the volume and pressure of the air that they contain. Thus, vertical load capacity increases with tyre size and inflation pressure. Figure 6 shows how soil pressure varies with depth for tyres of different sizes and carrying different vertical loads, but all operating at the same inflation pressure. The pressure contours extend deeper into the soil profile with increased vertical load even though the surface pressures are similar. This effect is the basis for the rule of thumb that surface soil compaction is related to the inflation pressure while subsoil compaction is related to the total vertical load on the axle.

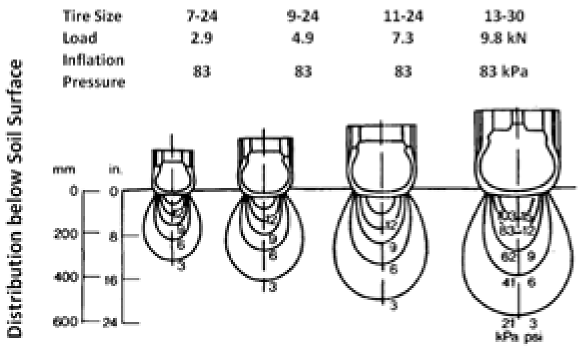

Figure 6 Distribution of major principal stresses in a soil under various tyre loads [13]

2.3 Traction Efficiency

To characterize the efficiency of an off-road vehicle in transforming the engine power to the power available at the drawbar, the traction efficiency is often used. It is defined as the ratio of the drawbar power P_d to the corresponding power delivered by the engine power P [13]. Improving traction efficiency, reduces costs through improved fuel efficiency and increases the productivity of off road vehicle that means providing the immediate fuel savings and improved performance. Figure 7 shows maximum power is available at the peak of each curve - a compromise between rolling resistance and wheel slip [14-15].

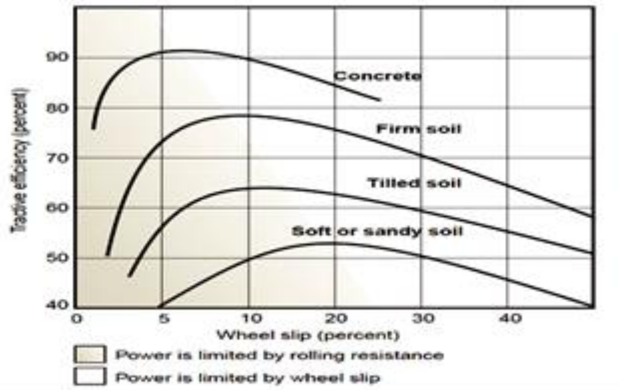

Figure 7 Maximum power is available at the peak of each curve - a compromise between rolling resistance and wheel slip [14-15]

The traction Efficiency η_d is defined as:

$$\eta_d = P_d / P = F_d \cdot V_a / P \qquad (1)$$

Where:

F_d - drawbar pull or force available at the drawbar = F - TF

V_a - actual speed of motion

F - thrust force

TF - towing or rolling resistance force.

Traction Efficiency is a product of three terms related to; efficiency of motion η_m, slip efficiency η_s, and the transmission η_t [13].

$$\eta_d = \eta_m \cdot \eta_s \cdot \eta_t \qquad (2)$$

This can be easily proved by substituting the input power *P* in equation (1) by the thrust force *F* multiplied by the theoretical speed V_t and divided by the transmission efficiency η_t, and the actual speed $V_a = V_t\,(1\text{-}s)$:

$$\eta_d = F_d \cdot V_a / P = F_d \cdot V_t (1-s) / F \cdot V_t / \eta_t$$

$$= (F_d / F)(1-s)\eta_t \qquad (3)$$

$$= \eta_m \cdot \eta_s \cdot \eta_t$$

Where:

$\eta_m = F_d / F$

$\eta_s = 1\text{-}s$

The efficiency of slip characterizes the power losses, and also the reduction in vehicle speed. Since slip increases with an increase of tractive effort and drawbar pull, the efficiency of slip decreases as the drawbar pull increases.

As can be seen from Eq. 3, the traction efficiency is the product of the efficiency of transmission, efficiency of motion, and efficiency of slip. In general, it exhibits a peak at an intermediate value of drawbar pull, as shown in Fig. 8. To increase the traction efficiency, optimization of the form and size of the vehicle running gear is of importance [13].

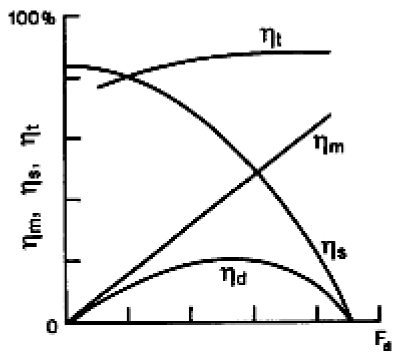

Figure 8 The variations of traction efficiency with Drawbar pull [13]

The longitudinal slip of the vehicle running gear, when a driving torque is applied, is usually defined by:

$$s = (1 - \frac{V_a}{\omega . r}) \cdot 100\% = (1 - \frac{r_e}{r}) \cdot 100\% \quad (4)$$

Where

s - the longitudinal slip

V_a - the actual vehicle speed

ω - the angular speed of the tyre

r - the rolling radius of the free-rolling tyre and

r_e - the effective rolling radius of the tyre.

2.4 Tyre-Soil Interaction

There must be some slip between the tyre and the soil surface for an efficient operation. Limited slip improves traction efficiency, which is the ratio of drawbar power to axle power and also provides a safety cushion against shock overloads that could damage the power-train; some wheel slippage is needed to reduce wear on the power train.

Figures 9 and 10 present the effects of wheel slip on sinkage and the tyre equivalent sinkage values as a function of the slip ratios. It can be seen that the equivalent tyre sinkage values are rising with the increase of the slip ratio and the trend becomes steeper when the slip ratio is larger [16-18].

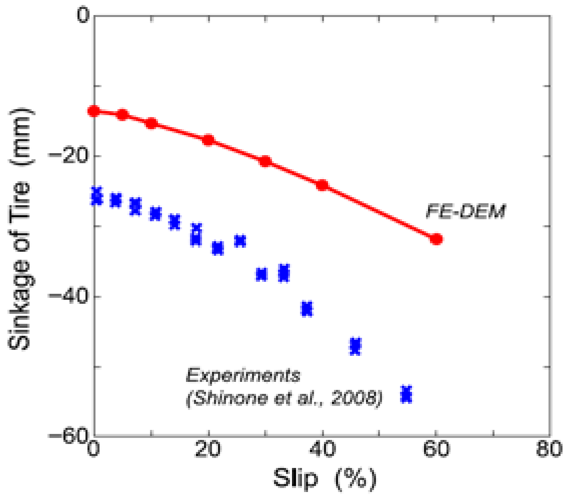

Figure 9 Sinkage versus slip for a grooved tyre [16-17]

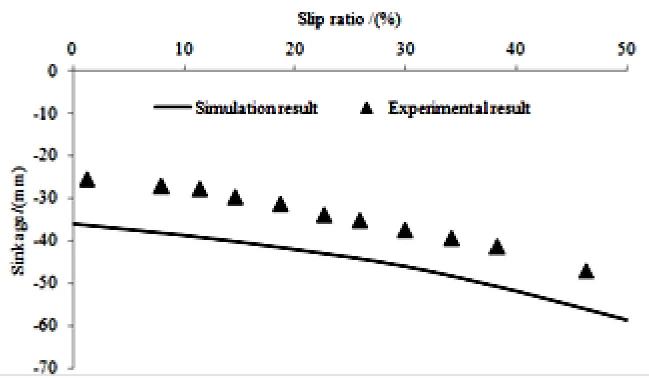

Figure 10 The relation between tyre sinkage and slip ratio [18]

Figure 11 illustrates the equivalent values (the average drawbar pull value under each slip ratio) of the drawbar pull as a function of the slip ratios. It can be seen that the drawbar pull shows an increasing trend when the slip ratio is less than 25%, and its value tends to be stable when the slip ratio is larger than 25% [18].

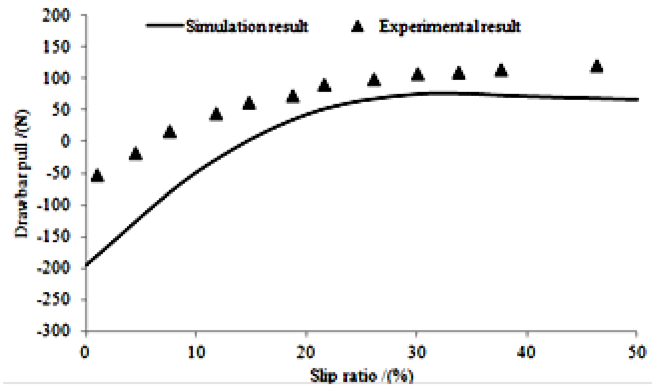

Figure 11 The relation between tyre drawbar pull and slip ratio [18]

As can be seen from Figs. 9 to 11, the tyre slip ratio has a strong effect on its running behaviour. The sinkage value of the tyre rises with the increases of the slip ratio due to the tyre digging effect. This leads to the increase of the bulldozing resistance which is the main resistance for tyre running on sand soil. The drawbar pull shows a steeper increasing trend when the slip ratio is less than 25% and the values tend to be stable when the slip ratio is larger due to the dramatic increase of the resistance under these slip ratio conditions. Floatation is defined as the ability of a vehicle to travel without excessive sinkage [11]. As sinkage increases, the drag forces become excessively large, and the vehicle will be immobilized. The higher the ground pressure generated by a loaded tyre moving on a soft soil the lesser will be its flotation as it will more sink in the soil, especially when its value is higher than the limit bearing capacity of the soil. Fig. 12 shows a schematic representation of the relationships of tyre stiffness, soil strength, and the resulting degree of tyre flotation [19].

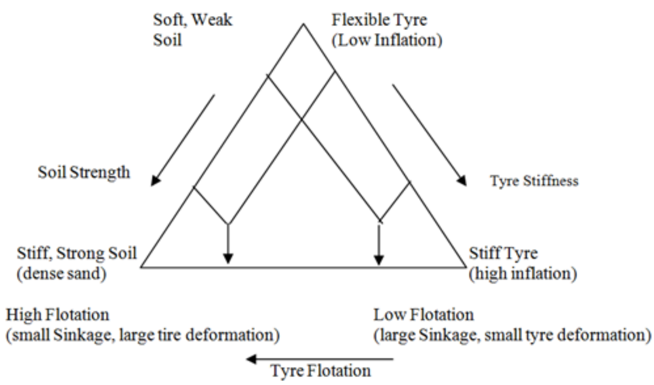

Figure 12 Tyre flotation diagram [19]

To get good tyre flotation when moving on soft soils like dry loose sands, the stresses generated by tyre loading should not overpass the limit bearing capacity of the soil. Fig. 13 shows, the point of transition from a relatively high to a much lower resistance to penetration on the curve relating the pressure under a loaded plate and the plate sinkage [19].

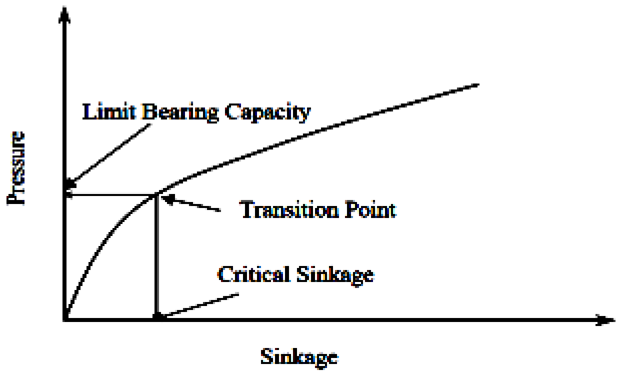

Figure 13 Limit bearing capacity of dry loose sand, [19]

Figure 14 shows the relationship between Effective contact area vs. tyre pressure at different tyre load for the same tyre and soil, whereas the effective contact area is revising proportional to the tyre inflation pressure.

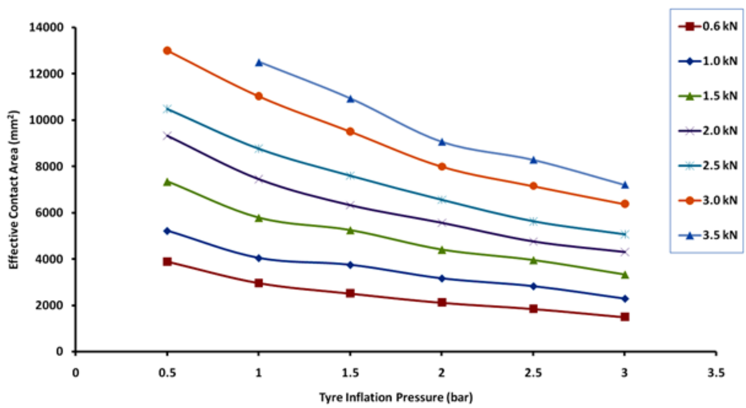

Figure 14 Effective contact area vs. tyre pressure at different tyre load [20]

From all of the previous figures it can be said that excessive tyre slip causes loss of power and accordingly excessive fuel consumption. On the other hand, when controlling the tyre slip by reducing the inflation pressure the tyre slip efficiency and accordingly its traction efficiency increases.

4. A NEW EMPIRICAL FORMULA

A trial to correlate empirical the measured results (collected data [21]) for slip and inflation pressure of tyre size 10.00-28 and drawbar pull has been done on loose sand. The software (Data Fit, version 6.1.10) was used to establish an empirical formula by correlating these values [22]. The new empirical formula that can be used to determine the drawbar pull of off road vehicles depend on two parameters, slip and inflation pressure and is written as:

$$F_d = 20.1 + 34.23\,S - 1.786\,S^2 + 0.052\,S^3 - 0.0008\,S^4 + 4.66\,S^5 - (286.3/\,P_i) + (292.74/\,P_i^2) - (93.63/\,P_i^3) + (9.42/\,P_i^4) \quad (5)$$

Where:
F_d - Drawbar pull, kg
S - Slip, %
Pi - Inflation Pressure, bar.

Figure 15 shows the influence of tyre inflation on the Drawbar pull at five pressures; 0.2, 0.4, 0.6, .0.8, 1.0 bar. As the figure shows, the gain in the drawbar pull force is much higher at low values of travel reduction (wheel slip), and that this gain is also much higher at very low pressures (0.2, 0.4 bar). A good accuracy has been achieved between the actual and the predicted values based on the above empirical formula for Drawbar pull.

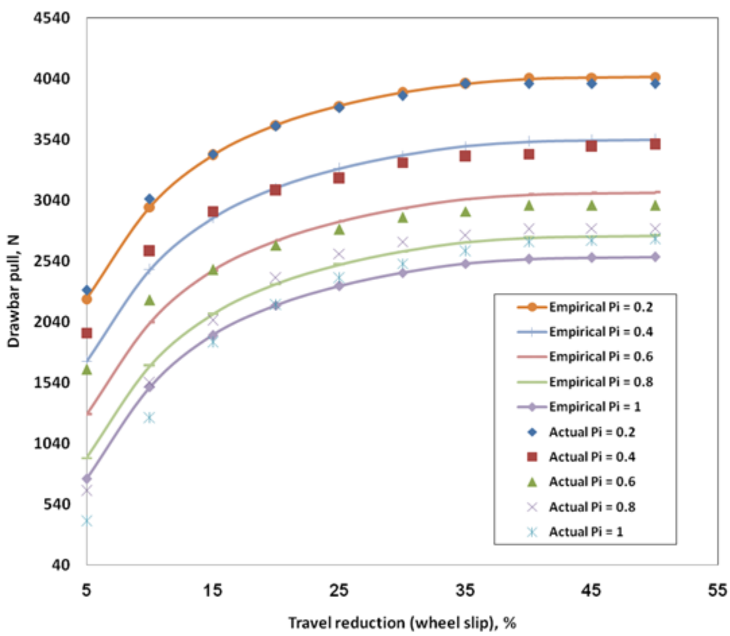

Figure 15 the influence of tyre inflation pressure on the drawbar pull

In this paper, we use Data Fit software version 6.1.10 to make sure from the results of the empirical formula and results of the program are shown in Table (1) and the Fig. 16 shows from the residual normal probability plot that the error terms are normal distribution.

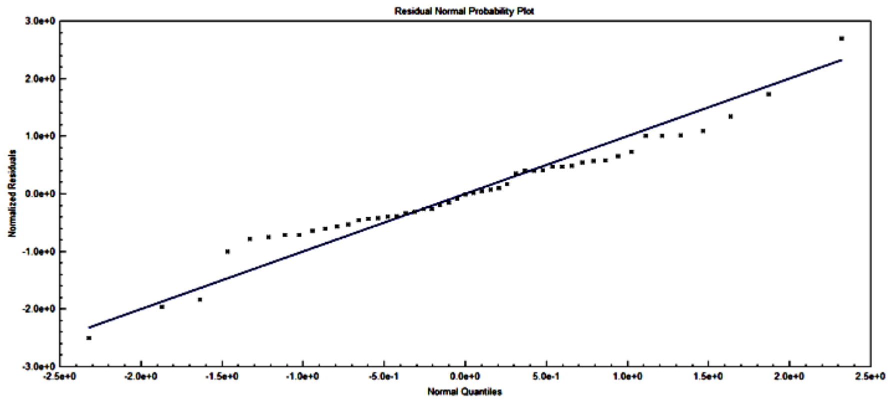

Figure 16 Residual Normal probability plot

Table 1 The statistical results of Data Fit Software

DataFit version 6.1.10				
Equation ID: a+b*x1+c*x1^2+d*x1^3+e*x1^4+f*x1^5+g/x2+h/x2^2+i/x2^3+j/x2^4				
Number of observations = 49				
Number of missing observations = 1				
Solver type: Nonlinear				
Nonlinear iteration limit = 250				
Diverging nonlinear iteration limit =10				
Number of nonlinear iterations performed = 9				
Residual tolerance = 0.0000000001				
Sum of Residuals = -1.12030562604559E-08				
Average Residual = -2.28633801233794E-10				
Residual Sum of Squares (Absolute) = 7476.85373157776				
Residual Sum of Squares (Relative) = 7476.85373157776				
Standard Error of the Estimate = 13.8460896373519				
Coefficient of Multiple Determination (R^2) = 0.9757194749				
Proportion of Variance Explained = 97.57194749%				
Adjusted coefficient of multiple determination (Ra^2) = 0.9701162768				
Durbin-Watson statistic = 0.863124596313696				
Regression Variable Results				
Variable	Value	Standard Error	t-ratio	Prob(t)

a	20.05459	239.6898	0.083669	0.93375
b	34.23221	11.70312	2.925049	0.00571
c	-1.78571	1.16031	-1.539	0.13188
d	0.051879	0.050336	1.030658	0.30905
e	-0.00078	0.000986	-0.79035	0.4341
f	4.66E-06	7.14E-06	0.652603	0.51784
g	-286.394	516.8445	-0.55412	0.58266
h	292.7395	387.7003	0.755066	0.45475
i	-93.6314	116.4156	-0.80429	0.42611
j	9.417882	11.53432	0.816509	0.41917

To better illustrate and tie all the parameters, the relationship is drawn in three dimensions as shown in Fig. 17. This graph can be used as an image in the proposed model and enables determining the appropriate tyre air pressure to obtain the maximum drawer pull.

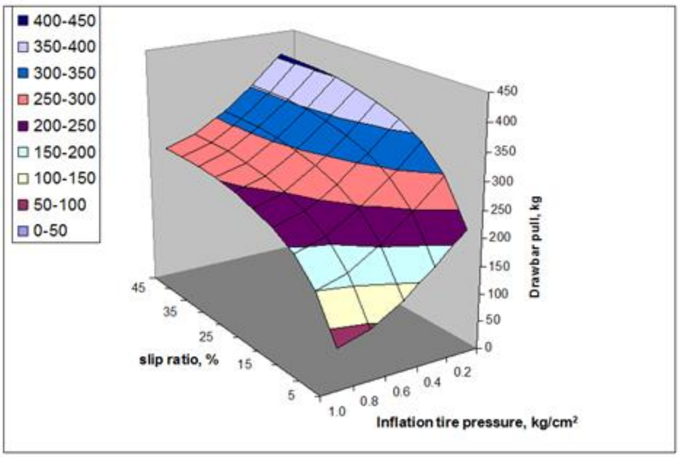

Figure 17 The Relationships of Drawbar pull, tyre inflation pressure, and slip

5. PROPOSED MODEL

The proposed model consists of; a control unit that receives the wheel speed sensor signals from each wheel and calculate the theoretical speed of each wheel and a radar gun sensor that measures the vehicle ground speed (actual travelling speed). By knowing the theoretical and actual vehicle speeds, the control unit can calculate the tyre wheel slip. The control unit also can determine the air pressure at each tyre by using a wireless pressure sensor for each wheel. From the stored data in the microprocessor of the control unit actuating signals will be operating the air solenoid valves to adjust the tyre pressure for obtaining the optimum drawbar pull. Figure 18 represents the layout of the proposed model and the Figure 19 shows the flowchart of the proposed model.

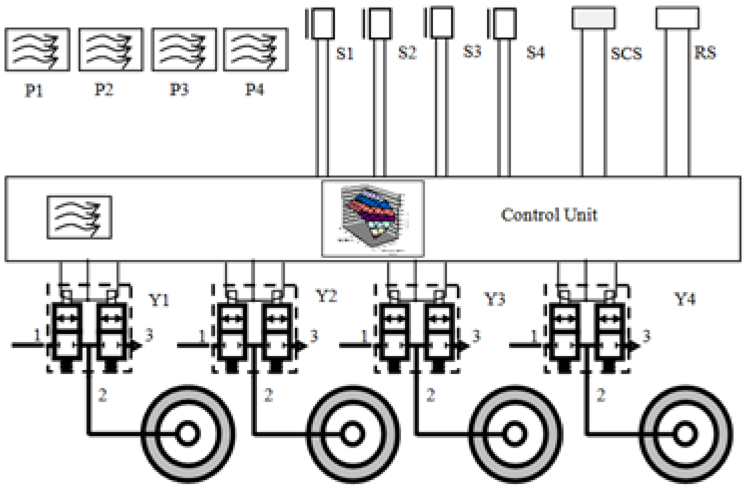

Figure 18 Layout of the proposed model for optimizing the tyre drawbar pull

Where:

P1: wheel tyre pressure wireless on front right wheel
P2: wheel tyre pressure wireless on front left wheel
P3: wheel tyre pressure wireless on rear right wheel
P4: wheel tyre pressure wireless on rear left wheel
RS: Radar gun sensor
S1: wheel speed sensor on front right wheel
S2: wheel speed sensor on front left wheel
S3: wheel speed sensor on rear right wheel
S4: wheel speed sensor on rear left wheel
SCS: Soil Compaction or Density Sensor
Y1: solenoid valve for front right wheel
Y2: solenoid valve for front left wheel
Y3: solenoid valve for rear right wheel
Y4: solenoid valve for rear left wheel

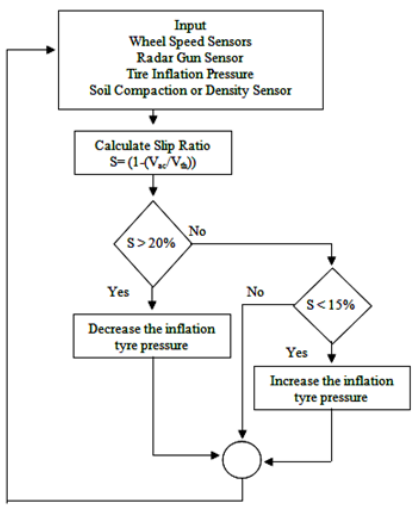

Figure 19 Flow chart of the proposed model

5. CONCLUSIONS

The present work introduces a new Empirical Formula that can be used to determine the drawbar pull as a function of tyre inflation pressure and slip. The proposed model that includes a closed loop control system with various sensors and solenoid valves in addition to the processor) can be applied on real vehicles to adjust a tyre inflation pressure according to the wheel slip to obtain optimum off-road vehicles` drawer pull and traction efficiency. Finally the tyre pressure control by sensing slip ratio, this reduces the tyre sinkage on the soil and thus reduces the rolling resistance and leads to lower fuel consumption, and also keeps the tyre from rapid wear and increase lifetime.

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NUMERICAL ANALYSIS OF THE CHILD LUMBAR SPINE MOVEMENTS IN THE MOTOR VEHICLE CRASH

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UDC:629.11.02/098

ABSTRACT: Seat belts in vehicles, for many years, have the task to reduce the level of injuries that can occur during traffic accidents. Although the number of children who die in traffic accidents decreasing, there are still some parents who incorrectly associated children to their seats. The most common injuries that occur in children are cervical spine fractures and lumbar spinal dislocations. We studied the correct and incorrect way binding belt child in the back seat. The three-dimensional model of lumbar spine (segment L4-L5) has been developed and analysed. The model consisted of two vertebral bodies and one intervertebral disc. Numerical solutions of von Misses stresses and displacements, occur as a result of vehicle crash, are calculated and analysed. With computer manipulation it is possible to simulate the behaviour of lumbar spine, and this may help to better understand the mechanical and physical characteristics this part of the body.

KEY WORDS: child seat belt, vehicle crash, lumbar spine, vertebral body, intervertebral disc

NUMERIČKA ANALIZA POKRETA LUMBALNOG DELA KIČME DETETA U SUDARIMA MOTORNIH VOZILA

REZIME: Pojasevi u vozilima, dugi niz godina, imaju zadatak da smanje nivo povreda koje mogu da nastupe tokom saobraćajnih nezgoda. Iako, je broj dece koja stradaju u saobraćajnim nezgodama u padu, i dalje postoje neki roditelji koji pogrešno vezuju decu u njihova sedišta. Najčešće povrede koje se javljaju kod dece su cervikalni prelomi kičme i lumbalna iščašenja. Istraživali smo pravilan i nepravilan način vezivanja pojasa dece na zadnjem sedištu. 3D model lumbalnog dela kičme (pršljenovi L4-L5) je razvijen i analiziran. Model se sastoji od dva tela pršljena i jednog međupršljenskog diska. Numerička rešenja von Mizesovih napona i pomeranja, nastali kao rezultat sudara vozila, sračunati su i analizirani. Računarskom simulacijom je moguće simulirati ponašanje lumbalnog dela kičme i ovo može pomoći boljem razumevanju mehaničkih i fizičkih karakteristika ovog dela tela.

KLJUČNE REČI: dečiji pojas, sudar vozila, lumbalni deo kičme, vertebralni deo, međupršljenski disk

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UDC: UDC:629.11.02/098

1. INTRODUCTION

A seat belt, as is known, has a role to protect vehicle passengers in case of a sudden stop or traffic accident. Restraint systems such as seat belts and airbags have a great role in decreasing the number of children who die in traffic accidents [1]. Child restraint systems are often used incorrectly. An estimated 46% of car and booster seats are misused in a way that could reduce their effectiveness [2]. The most common injuries that occur in children are cervical spine fractures and lumbar spinal dislocations (Figure 1).

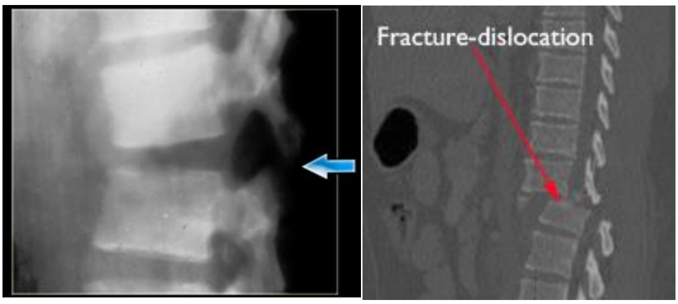

Figure 1 Spinal injuries

Cases of serious cervical and lumbar spinal cord injury have been described for many years [3]. These injuries occur when a child uses the wrong shoulder belt, or when the shoulder belt is not present (Figure 2) [4], [5].

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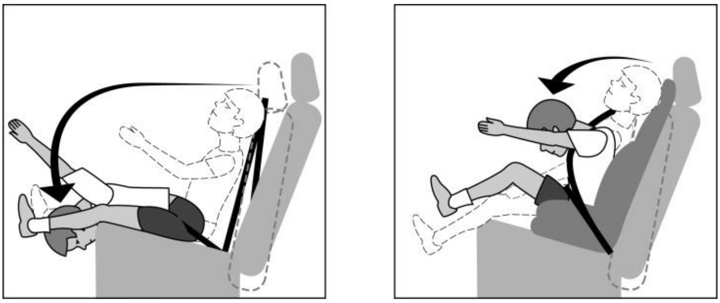
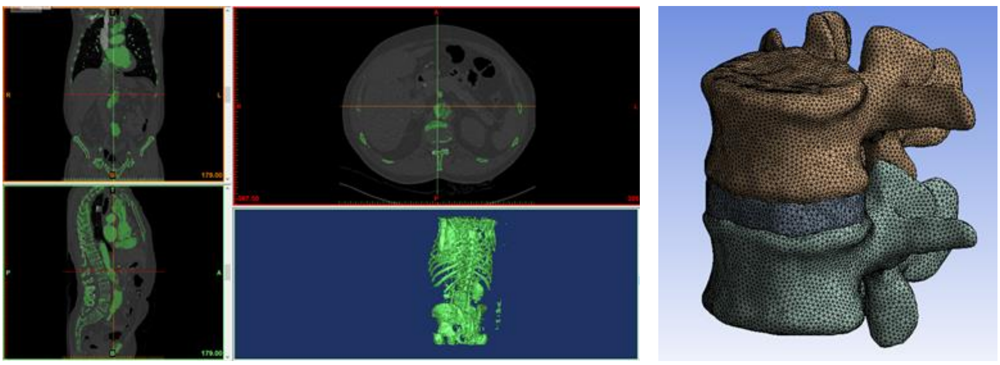


Figure 2 Incorrect and correct the seat belt use

The aim of this study was to analyse the behaviour of the lower spine during emergency braking in two cases, using the finite element. 3D model of a L4-L5 vertebra has been tested in bending to determine the displacements and von Misses stresses. In this way, the numerical simulations can determine the degree of injury to children in a car accident.

2. MATERIALS AND METHODS

A 3D computer model of a L4-L5 vertebra was developed using the CT scans. The CT scans were read into Mimics visualization software, where the images were segmented by thresholding to obtain vertebra model, with intervertebral disc (Figure 3).



a) *b)*

Figure 3 The process for the 3D FE model: a) CT scan and 3D reconstruction of the CT scans, and b) meshing of the 3D FE model

After creating a 3D model, we used Ansys R14.5 to generate 3D mesh (Figure 2b). Linear tetrahedron was used as the final element. Finite element mesh consists of three groups of elements: finite elements that represent cortical bone, finite elements that represent nucleus and finite elements that represent annulus. Mechanical properties assigned to the each material are summarized in Table 1 [6], [7].

Table 1 Material properties of components of the spine

Name of component	Young's Modulus [MPa]	Poisson's ratio
Cortical bone	12000	0.3
Nucleus	1	0.49
Annulus	4.2	0.45

The boundary condition was defined by fixed nodes at the bottom of the model, while on the upper surface of the model set the certain value of the force. Using Hyper Physics [8], we got the value of the force, that acting on the body in car crash (4000 N, calculated for children from 30 kg weight and speed of the car 70 km/h). In the case when the belt is used properly, it has limited the movement the model to 100 mm.

One of the basic principles of continuum mechanics is the principle of virtual work. Starting from the equilibrium equations [9] by applying the boundary conditions can be equal to the virtual work of internal and external forces:

$$\delta W_{\text{int}} = \delta W_{ext} \tag{1}$$

Virtual work of the previous equation in matrix form can be written as:

$$\delta W_{\text{int}} = \int_V \delta \mathbf{e}^T \boldsymbol{\sigma} dV \qquad \delta W_{ext} = \int_V \delta \mathbf{u}^T \mathbf{F}^V dV + \int_{S^\sigma} \delta \mathbf{u}^T \mathbf{F}^S dV + \sum_i \delta \mathbf{u}^T \mathbf{F}^{(i)} \tag{2}$$

Applying the principle of virtual work and the constitutive relations for linear elastic material in matrix form

$$\boldsymbol{\sigma} = \mathbf{Ce} \tag{3}$$

and by applying the concept isoparametric interpolation [10] in the finite element, we can write the equation of equilibrium finite elements

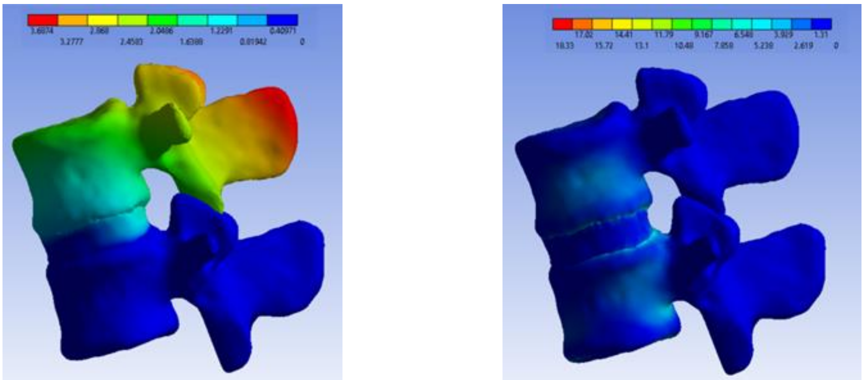
$$\mathbf{KU} = \mathbf{F}_{ext} \tag{4}$$

where K is element stiffness matrix, C - elastic constitutive matrix, e = BU - matrix deformation, U - displacements at the nodes, F_{ext} - external forces in the element nodes.

In the linear analysis of solids a basic assumption is that the moving solids is infinitesimally small and that the material is linearly elastic. Also, the assumption is that the nature of the boundary conditions remain unchanged under the action of external loads. Under these assumptions, the equations of equilibrium is derived for finite element structural analysis.

3. RESULTS

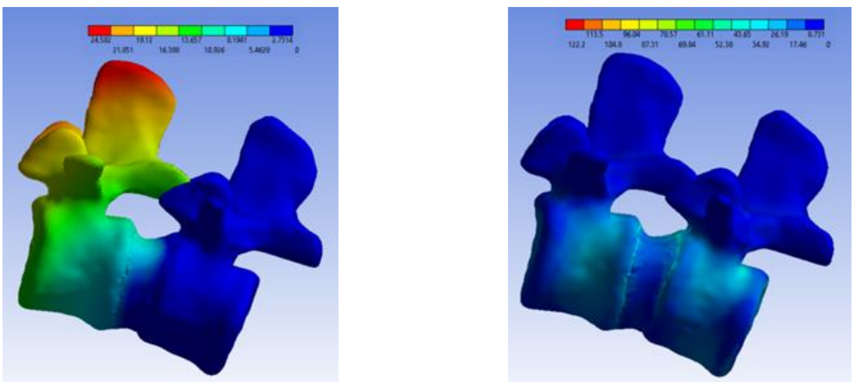
In this this section, we present the results of numerical simulation. We investigated two cases. Figure 4 show results of the first numerical analysis – simulation of a correct seat belt use.



a) *b)*

Figure 4 Numerical results of case 1: a) displacement [mm], b) Von Mises stress distirbution [Pa]

As can be seen, the greatest value of displacement of the upper vertebra part is 3.68 mm. In the area near the spinal cord recorded the movement of the annulus of 1.35 mm. Figure 4b present Von Mises stress distribution along studied model. The highest recorded value of this stress is 18.73 MPa, in the area of contact vertebra body and intervertebral disc. These zones leads to cervical spine fractures, so it is of great relevance correct use of the seat belt. Figure 5 shows stress distribution for second case.



a) *b)*

Figure 5 Numerical results of case 2: a) displacement [mm], b) Von Mises stress distirbution [Pa]

Improper use seat belts, in the event of an car accident, leading to large displacement of parts of the spine. As can be seen from Figure 5, the greatest displacement go to enormous 24.52 mm. Moving the intervertebral disc go to 13.6 mm. The von Misses stress reaches a value of 122.2 MPa. All this leads to serious damage to the spine and improper functioning of its parts.

4. CONCLUSIONS

The FEA performed in this study demonstrated pattern of von Misses stress distribution and displacement through the lumbar spine (segment L4-L5) during car accident. We studied the correct and incorrect way binding belt child in the back seat. Results of this study showed that the displacement of L4 vertebra body in the first case is 3.68 mm, which is a good result and secure value for the spine. The highest von Misses stress has a value 18.73 MPa. Improper use seat belts, in the event of an car accident leading to large displacement of the L4 vertebra body. Greatest value in this case has 24.52 mm. Intervertebral disc has a large displacement, even 13.6 mm, which leads to cervical spine fractures. These results give a clearer picture of the severity of injuries of the spine during sudden braking of the car. It is necessary that everyone understand the seriousness of the problem.

ACKNOWLEDGMENTS

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THERMAL RADIATION BETWEEN THE DRIVER AND THE VEHICLE CABIN INTERIOR

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UDC: 629.113;614.8.084

ABSTRACT: Thermal radiation is one mode of the thermal exchange between the passengers and the interior surfaces of the vehicle's cabin, equally important as convection, conduction and latent heat exchange. The parameters that influence radiative heat exchange between the human body and cabin's surfaces are discussed in this paper. The influence of the radiative heat exchange on human thermal sensation is explained. Characteristics of the surrounding surfaces and of the human body surfaces as well quantification of the radiation heat transfer in typical cabin interior conditions are given. The values are based on experimental and numerical researches in motor vehicles. The results show importance of thermal radiation and its high influence on thermal sensation in vehicles.

KEY WORDS: motor vehicle, cabin, thermal comfort, thermal radiation, mean radiant temperature

RAZMENA TOPLOTE ZRAČENJEM IZMEĐU VOZAČA I UNUTRAŠNJOSTI KABINE VOZILA

REZIME: Toplotno zračenje je jedan oblik razmene toplote između putnika i unutrašnjih površina kabine vozila. Ovaj vid razmene toplote je jednako važan kao i razmena toplote konvekcijom, provođenjem i latentna razmena toplote. U ovom radu su obrađeni parametri koji utiču na toplotno zračenje između čovekovog tela i površina kabine i navedene su osnovne karakteristike unutrašnjih površina i površine čovekovog tela sa aspekta toplotnog zračenja. Prikazom konkretnih vrednosti razmene toplote zračenjem pod odabranim graničnim uslovima objašnjen je uticaj na toplotni osećaj čoveka. Vrednosti su zasnovane na eksperimentalnim i numeričkim rezultatima istraživanja u motornim vozilima. Rezultati su pokazali da na toplotni osećaj vozača motornog vozila veći uticaj ima vrednost temperature okolnih površina nego eventualna neuniformnost temperatura površina u kabini.

KLJUČNE REČI: motorno vozilo, kabina, toplotni komfor, toplotno zračenje, srednja temperatura zračenja

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1. INTRODUCTION

Air temperature, radiant temperature, humidity and air movement are the four basic environmental variables that affect human response to thermal environments and therefore his thermal sensation. Combined with the metabolic activity and clothing, they provide the six fundamental factors that define human thermal environments. They are used to calculate heat transfer to and from the human body. Actually, a person feels heat exchange not the air temperature or the air velocity. Radiative heat transfer between the human body and the surrounding has the same significance as the convective heat transfer influenced by the air temperature and the air movement. Heat is exchanged by radiation between all bodies, and there is a heat flow from a hot to a cold body depended on the temperature difference between the two bodies and to emissivity of the surfaces.

Cabin of motor vehicle is a special environment due to confined space and possible occurrence of surfaces with high temperature, significantly higher that can be encountered in buildings. Therefore it is very important to include the radiative heat exchange in investigation of thermal conditions inside the vehicle cabin. In the case of cabin of passenger car, the interior thermal environment has significant impact on driver's performance, hence on driving safety. It must be bear in mind that even under moderate outside conditions the closed cabin act like green house and its closed interior could become unpleasant, unbearable and even dangerous [1], [2], [6], [8], [9]. The AC system is not able to directly change mean radiant temperature, except by decreasing the temperature of the inner surfaces, although very slowly.

Experimental determination of local heat fluxes on human body surface demands the use of complex and expensive measurement equipment and test facilities [1], [3], [4], [6], [10]. The other way is to simulate these processes in virtual experiments. This paper focuses on numerical modelling of radiative heat exchange between the driver and passenger car cabin interior, but excluding the effects of the solar radiation transmitted through a cabin glazing.

2. METHOD

The simulations were done in CFD software STAR-CCM+. The software includes the Surface-To-Surface Gray Thermal radiation model for simulation of diffuse radiation independently of wavelength with non-participating media. With this model, radiation properties of the media and surrounding surfaces are considered the same for all wavelengths. The air that fills the space between the surfaces does not absorb, emit or scatter radiation.

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The surface properties are emissivity, reflectivity, transmissivity and the surface temperature. In this case, for the thermal radiation analysis inside the vehicle cabin, all surfaces are considered as an opaque for the thermal radiation (zero transmissivity) and absorptivity is equal to emissivity (Kirchhoff's law).

2.1 Theoretical background

Sensible heat exchange between the driver and the interior of the cabin directly contributes to the thermal sensation and takes place by convection, conduction and thermal radiation, including the solar radiation passing through glass of a cabin. To make thermal conditions comfortable, a driver is able to directly influence only the heat transfer by forced convection by changing modes of air flow over the surface of his body. This system changes the air temperature in the cabin by mixing ventilation. Indirectly, the temperature of interior surfaces will be changed too, although much more slowly [9].

When surrounded by surfaces with higher temperature than that of their skin and clothing (t_{sk}, t_{cl}), a person receives the heat by thermal radiation (q_r). Thermal radiation flux from hot surrounding surfaces depends on the wall surface temperature and the emissivity of the wall (ε). The wall temperature and its emissivity are expressed by mean radiant temperature (t_{mr}) and linear radiative heat transfer coefficient (h_r) **Error! Reference source not found.**, **Error! Reference source not found.**:

$$q_r = h_r \cdot f_{cl} \cdot (t_{mr} - t_{cl}), \text{ W/m}^2 \qquad (1)$$

$$h_r = 2.88 \cdot \varepsilon \cdot \sigma \left(273.2 + \frac{t_{cl} + t_{mr}}{2} \right)^3, \text{ W/m}^2\text{K} \qquad (2)$$

The mean radiant temperature is the uniform temperature of an imaginary enclosure in which radiant heat transfer from the human body is equal to the radiant heat transfer in the actual non-uniform enclosure [5]. This parameter has equal significance for heat exchange between the human body and the environment as an air temperature. It depends on surface temperatures, surface shapes and emissivity. The emissivity of non-metallic surfaces is generally high, 0.9 and higher, just like the emissivity of the human skin and clothing [9].

2.2 The model

The interior of the cabin is modelled on the shape and dimensions of middle class passenger hatchback car, with significant simplification of the cabin geometry. The model was made in CAD software CATIA. The interior of the cabin was discretized in about 168,000 finite volumes and about 154,000 surfaces. Fig.1.

The driver is modelled as a virtual thermal manikin. The virtual thermal manikin was developed on Faculty of Technical Sciences – University of Novi Sad (VTMFTS) [7]. The CAD model of the virtual thermal manikin (VTM) is a simplified humanoid in the sitting posture. Main body dimensions are adopted from CATIA database for a 50th percentile European male. According to the chosen sizes of the body, the VTM is 1.74 m tall and weighs 68 kg. The area of VTM body surface in sitting position is 1.796 m^2. The manikin's body is divided into 18 segments, (head, neck, chest, back, etc.) in order to monitor the heat exchange on individual segments (Fig. 2). A method with constant temperature of the manikin's body surface was used. The driver body surface is divided into about 13,800 surfaces.

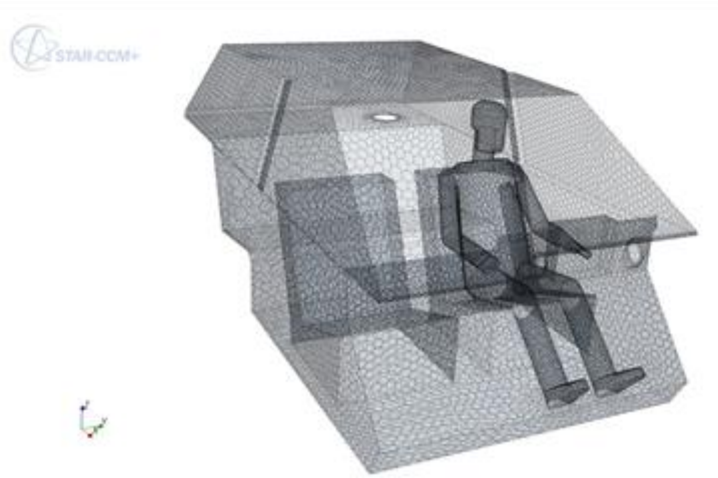

Figure 1 Meshed model of the passenger car cabin with driver

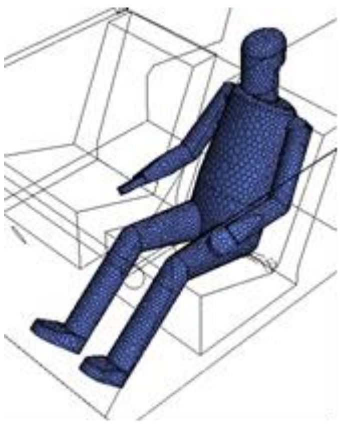

Figure 2 The virtual thermal manikin VTMFTS

3. BOUNDARY CONDITIONS

The manikin's surface temperature was 34°C for bare skin (head, hands and lower arms) and 30°C for the segments covered by clothing. In all virtual experiments only the driver was present.

It was presumed that the emissivity of all interior surfaces as well as of human body is 0.95. This value is taken as a typical value for materials involved in radiative heat exchange inside vehicle cabin (glass, polymers, clothing and human skin) [9].

Boundary conditions for the virtual experiments are given in Table 1. Moderate conditions are the conditions where the air temperature is 26°C, while in hot conditions it is assumed that the air temperature is 34°C. In moderate and hot conditions all surfaces have the same temperature, equal to the air temperature. In non-uniform conditions some of the surfaces are on the higher temperature due to solar radiation or heat gain from the powertrain. The surface temperatures are chosen according to boundary conditions proposed by relevant standards combining with empirical data [1], [8], [9], [11], [12], [13].

Table 1 Temperatures of the cabin interior surfaces (°C)

	moderate	moderate non-uniform	hot	hot non-uniform
windshield	26	34	34	42
instrument panel	26	34	34	42
firewall	26	34	34	42
side window	26	26	34	34
seat	26	26	34	34
ceiling	26	34	34	42
other interior surfaces	26	26	34	34

4. RESULTS AND DISCUSSION

The thermal radiation heat flux on individual segments of the driver's body and mean radiant temperatures are the main results obtained by the simulations post-processing. In Fig. 3 the thermal radiation heat fluxes are graphically presented. The negative values indicate heat gain by the thermal radiation. Values on the line portion between two body segments have no meaning, of course.

It can be noted that even under the uniform conditions the highest heat exchange is on segments that are directly exposed to the surrounding surfaces (head, arms and hands). The non-uniformity of the temperatures of the surrounding surfaces under chosen conditions obviously has less influence than the total heat transfer by thermal radiation. Thermal radiation flux on the driver's body in moderate uniform conditions and in hot non-uniform conditions are shown in fig. 4 and 5, respectively (Note: the sign of the flux is opposite to that in the graph in Fig. 3). Strong thermal radiation on head and lower legs due to high temperature of surrounding surfaces can be noticed on fig. 5.

Mean radiant temperatures for individual segments of the driver's body are given on graph in Fig. 6. Distributions of mean radiant temperature on the driver's body in moderate uniform and in hot non-uniform conditions can be seen on Fig. 7 and Fig. 8. For the same boundary conditions, the distribution of local mean radiant temperature is more uniform than thermal radiation heat flux. The cause is difference in values of linear radiative heat transfer coefficient between individual body segments (Eq. 2).

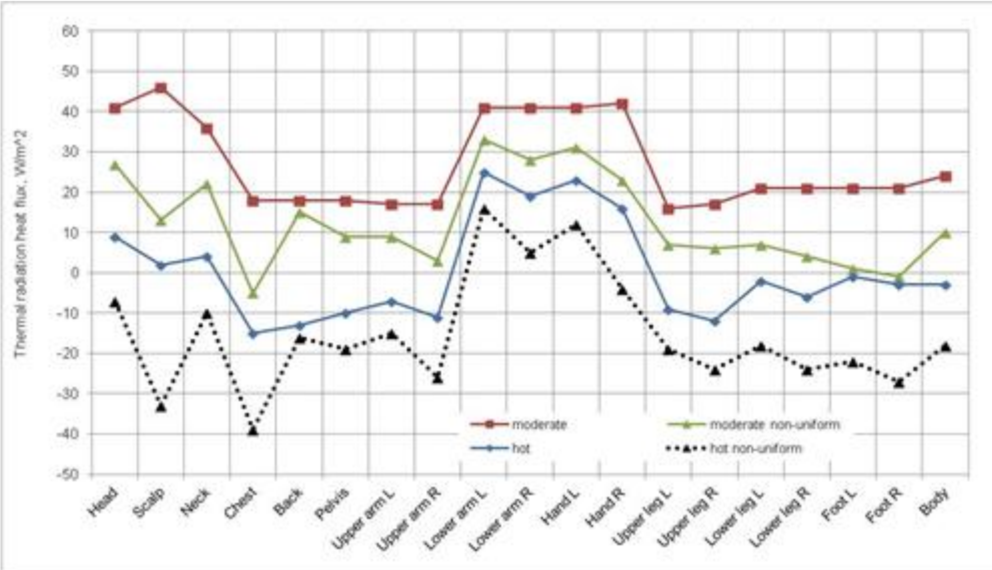

Figure 3 The thermal radiation heat flux on individual segments of the driver's body

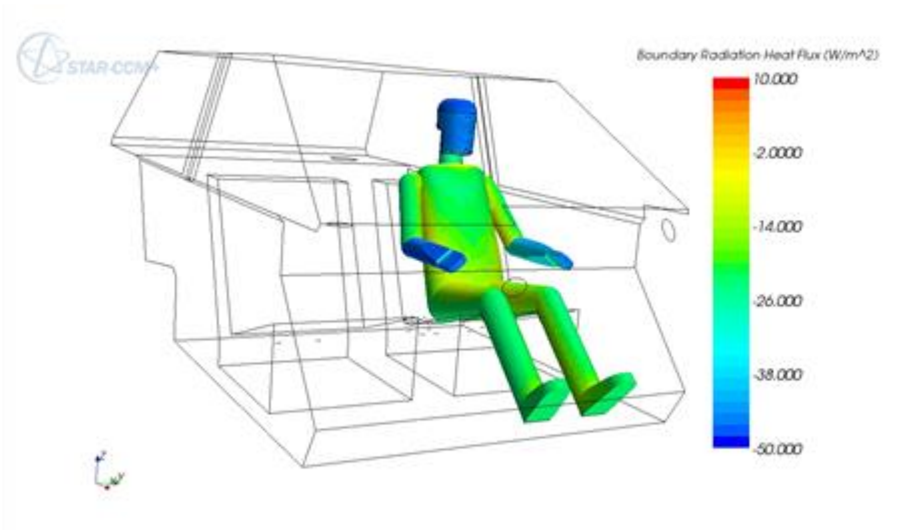

Figure 4 Visualisation of thermal radiation flux on the driver's body in moderate uniform conditions

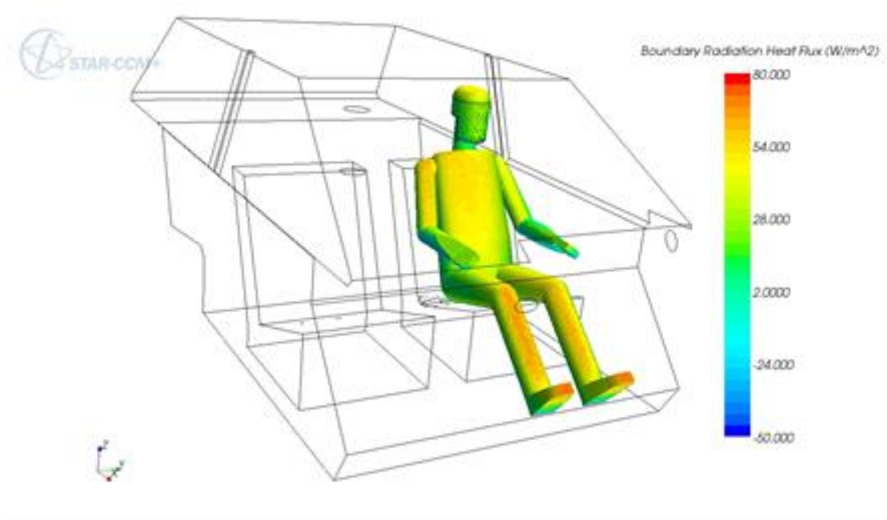

Figure 5 Visualisation of thermal radiation flux on the driver's body in hot non-uniform conditions

The values mainly correspond to the temperature of the surrounding surfaces, due to high value of emissivity. In the experiments performed by Ružić [6] and Agošton [1] under the hot outdoor conditions with solar radiation, the values of mean radiant temperatures that are encountered inside the cabin of passenger car were in the range of 35 to 45°C.

The relationship between the thermal radiation heat flux and mean radiant temperature is given in Eq. 1. Under the chosen boundary conditions, average values of linear radiative heat transfer coefficient for whole body are in range from 5.1 to 6.6 W/m^2K. This value is slightly higher than the values for typical indoor temperatures [4], [5], [7], [10], [14]. Because of specific environment, the values can be taken as an appropriate for the purpose of research of thermal conditions inside the vehicle cabin.

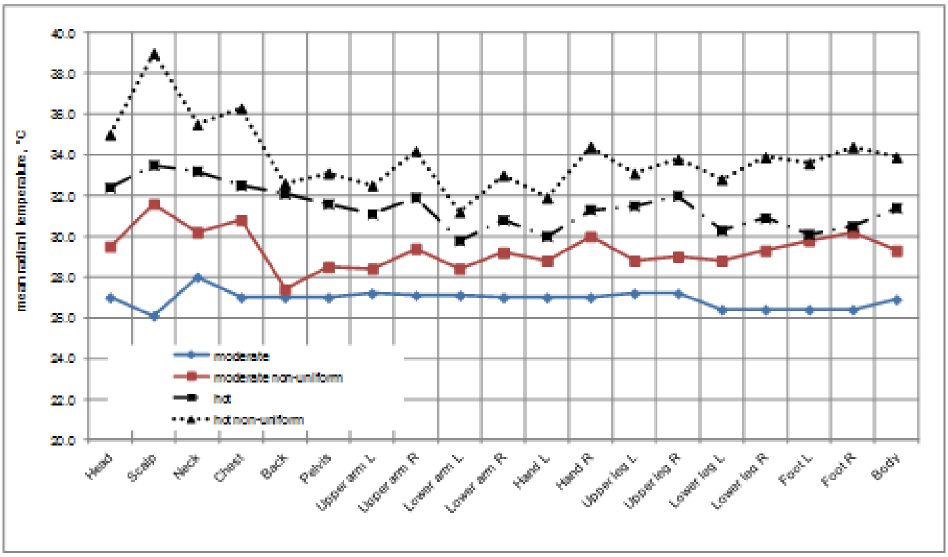

Figure 6 Mean radiant temperatures on individual segments of the driver's body

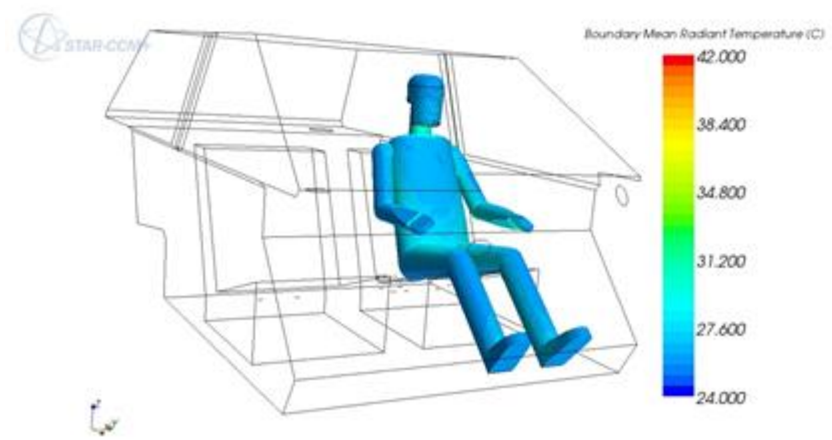

Figure 7 Visualisation of mean radiant temperature on the driver's body in moderate uniform conditions

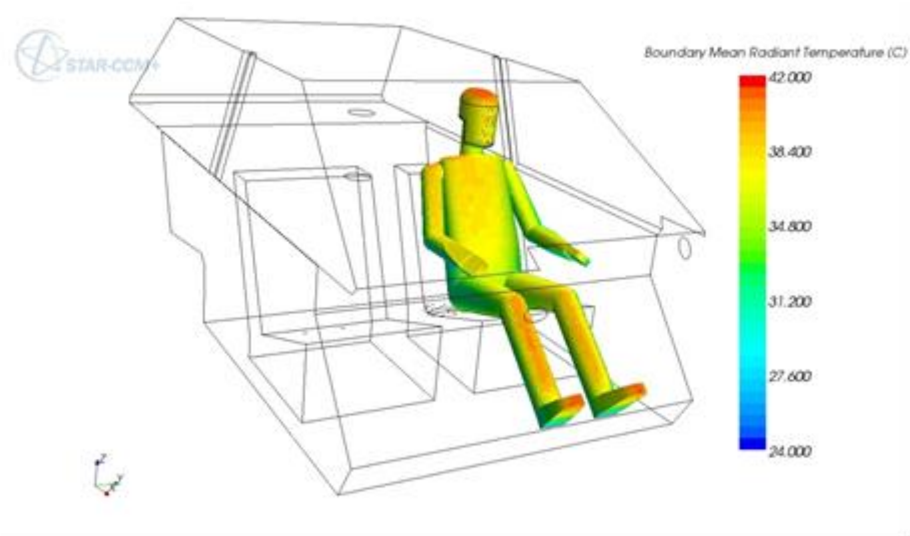

Figure 8 Visualisation of mean radiant temperature on the driver's body in hot non-uniform conditions

4. CONCLUSIONS

The influence of boundary conditions on thermal radiation between a driver and vehicle interior was analysed using the CFD software STAR-CCM+. The highest heat exchange occurs on segments that are directly exposed to the surrounding surfaces with high temperatures. Those body segments are head, arms and hands, i.e. the segments that are not covered by the clothing. The non-uniformity of the temperatures of the surrounding surfaces under chosen conditions obviously has less influence than the total heat transfer by thermal radiation.

In modelling of thermal radiation, correct data about surface emissivity and temperature are very important for accurate simulations. The values of linear radiative heat transfer coefficient obtained by the simulation post-processing are slightly higher than the values for typical indoor temperatures given in the literature, but because of specific environment, the values can be taken as an acceptable making the method suitable for further research of thermal conditions inside the vehicle cabin.

The advantages of the simulation method presented in this paper are the simplicity and independence from other modes of heat transfer. Although the gray thermal radiation model was used, the radiation can be modelled as spectrum-dependent.

For achieving accurate prediction of thermal radiation by simulations it is crucial to have comprehensive data about radiative properties of materials and boundary conditions. In any case, the numerical values obtained from the simulations should be considered for comparison purposes only, and validation of the numerical model must be done by physical experiment.

ACKNOWLEDGMENT

This work was supported by Serbian Ministry of Education, Science and Technological Development under Grant TR35041 - "Investigation of the safety of the vehicle as part of cybernetic system: Driver-Vehicle-Environment". The authors wish to thank to Department for Energy and Process Engineering at the Faculty of Technical Sciences – University of Novi Sad, for enabling the use of the CFD software Star-CCM+.

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THE DEVELOPMENT OF MAGNETIC GEARS FOR TRANSPORTATION APPLICATIONS

Slavica Miladinović[1], *Lozica Ivanović, Mirko Blagojević, Blaža Stojanović*

UDC:629.3.032.2;621.8.038

ABSTRACT: The gears, where the power and torque transmissions are performed with no contact and with help of the magnetic forces, are called magnetic gears. With this gears, unlike the mechanical gear transmissions, there are no noise, vibrations and friction, so therefore, there is no need for lubrication and maintenance costs are considerably lower. Two basic types of magnetic gears are: converted and magnetic gears with variable magnetic field. Magnetic gears are made of iron, boron and neodymium alloy, which allows to obtain a permanent magnet for maximum power magnetisation. This paper shows the outline of the magnetic gear development, their classification and characteristics, where the gear ratio and torque density are the most important. Also, the examples of application of magnetic gears in automotive and transportation industry are given in the paper.

KEY WORDS: magnetic gears, gear ratio, torque density, transport, automotive industry

RAZVOJ MAGNETNIH ZUPČANIKA ZA PRIMENU U TRANSPORTU

REZIME: : Prenosnici kod kojih se prenos snage i obrtnog momenta vrši bezkontaktno uz pomoć magnetnih sila nazivaju se magnetni prenosnici. Kod ovih prenosnika, za razliku od mehaničkih zupčastih prenosnika, nema buke, vibracija i trenja, pa samim tim nije potrebno podmazivanje i troškovi održavanja su znatno manji. Dve osnovne vrste magnetnih prenosnika su: konvertovani i magnetni prenosnici sa promenljivim magnetnim poljem. Magnetni prenosnici se izrađuju od legure gvožđa, bora i neodimijuma, koja omogućava da se dobije stalni magnet za maksimalne snage namagnetisanja. U ovom radu je prikazan kratak pregled razvoja magnetnih prenosnika, njihova podela i karakteristike, od kojih su najvažnije prenosni odnos i gustina obrtnog momenta. Takođe, dati su i primeri primene magnetnih prenosnika u automobilskoj i transportnoj industriji.

KLJUČNE REČI: magnetni prenosnici, prenosni odnos, gustina obrtnog momenta, transport, automobilska industrija

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1. INTRODUCTION

The power transmission is mechanical in most machines, and it is commonly achieved in the use of gear transmissions. Mechanical gear transmissions have a high torque density, but the friction occurs in them, which is often the cause of the gear failure. Also, the noise, heat and vibration are present, so the reliability of these gears is reduced.

Nowadays, it is more and more taken care of the energy conservation, and therefore the environment as well, when designing new products. The goal is to reduce the noise, vibration, to simplify maintenance more, reduce heat and reduce dimensions. The magnetic gears are the new type of gears, which attract the attention of the constructors because of the possibility to overcome some of these problems. These are non-contact gears, where the power and torque transmission is achieved with the help of magnetic forces. Friction, wear and fatigue are not present in magnetic gears, they do not require lubrication, and they can be applied as a protective mechanism against overloading. They can operate in a wide temperature range, from -270°C to 350°C. Also, the operation is reversible, so the same device, in which they are installed, can be used as a reducer and as a multiplier.

The concept of magnetic gear was proposed about a hundred years ago. Their main advantage, in comparison to the conventional gears, the lack of contact and wear of teeth, was the reason enough for the further development of magnetic gears. However, the low efficiency, complex structure and high costs of their making, represented a significant problem. The production of magnetic gears for general industrial applications was enabled with the development of new magnetic materials of high magnetic permeability, the new precise production techniques and advanced modelling tools. Thus, the number of researchers interested in the development of structural solutions and performances of magnetic gears has grown. Historical overview of magnetic gears, as well as achievements accomplished in this area, has been presented in the literature [1]. There are a large number of papers on the topic of magnetic gears. Figure 1 shows the number of papers published from 1900 to 2015, obtained from the literature [1, 2] and the available data on published papers.

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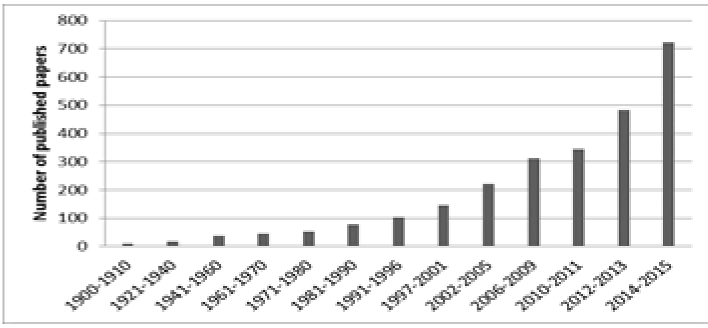


Figure 1 Statistics of published works

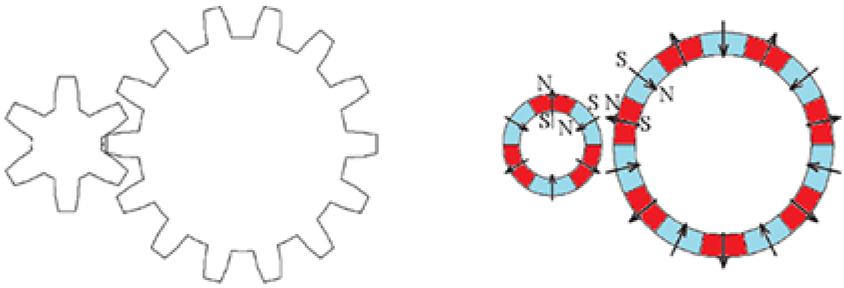
The number of papers dedicated to magnetic gears has increased exponentially over the last two decades, and the development of technology has allowed us to overcome many of the first problems.

2. STATE OF THE ART OF MAGNETIC TRANSMISSION

Different types of gears are used in industry for power and torque transmission. The gears with which the power transmission is realized by meshing of the gear teeth are called mechanical gears. The first such gears appeared more BC. Today, mechanical gears have a very broad application. The main advantages of these gears are that they are easy to make and that they have high efficiency, but disadvantages include high noise, friction, maintenance costs, vibration and heating.

With the development of technology, the aim is to develop other ways of power and torque transmissions, whereby the noise, vibration, maintenance costs, etc. would be lower. One of those ways is the use of magnets in the power transmission.

The magnet, as the power transmission device, was suggested for the first time by Armstrong C. G. in 1901 in his patent number 687292 [3]. The power transmission principle in magnetic gear devices is similar as with mechanical ones, except that the gear is not made with teeth meshing but without the contact, by applying magnetic force. Magnetic forces are obtained by the current flowing through the coil windings that are placed on the driving gear teeth. In addition to magnetic gears, whose gears rather resemble conventional cylindrical gears (figure 2) [4], there are concepts of magnetic gears resembling mechanical planetary gears. Magnetic planetary gears were first introduced in the patent from 1916 [5]. At the end of the 20th century, Ackerman had patented its magnetic planetary gear solution given in [6].



a) *b)*

Figure 2 a) Mechanical spur gear and b)Permanent-magnet gear [4]

There are many more patents on the topic of magnetic gears. Among them, there is a patent of cylindrical magnetic gears, published by Hetzel in 1974 [7], as well as the planetary gear patented by Mabe in 1991 [8]. Kikuchi & Tsurumoto experimented in 1993 with magnetic worm gears [9], and Yao et al. conceived the magnetic bevel gears in 1996 [10].

It is known that the realization of magnetic gears is ascribed to the implementation of a permanent magnet that can produce permanent flux and magnetic field, which makes it possible to achieve non-contact torque transmission. The ferrite was used in the beginning as the material for permanent magnets, and its good properties are low cost and easy production, while its disadvantages are low magnetic induction and transmission of low torque. With appearance of the new material neodymium-iron-boron (NdFeB), who had much better characteristics than ferrite, the magnetic gears came again into the limelight of the scientists in 1980s and their development was intensified.

The advantages of magnetic gears enabled the diversity of their practical application. The examples of these gears in hybrid vehicles are given in [11, 12, 13]. The Magnomatics Company developed a combination of motor and gear, which was named Pseudo Direct Drive, as well as MAGSPLIT, which was applied in hybrid vehicles [14].

3. TYPES OF MAGNETIC GEARS

Magnetic gears are divided into two types, as following: converted and magnetic gears with variable magnetic field.

Converted magnetic gears, which are also called the magnetic gears with direct effect, by its shape are reminiscent of the mechanical ones, except that instead of teeth they have magnets. Many magnetic gears can be classified in this group, and some of them are: magnetic worm gear, magnetic rack and pinion, magnetic bevel gear and magnetic spur gear (external and internal). Figure 3 shows a comparative view of magnetic and mechanical gears.

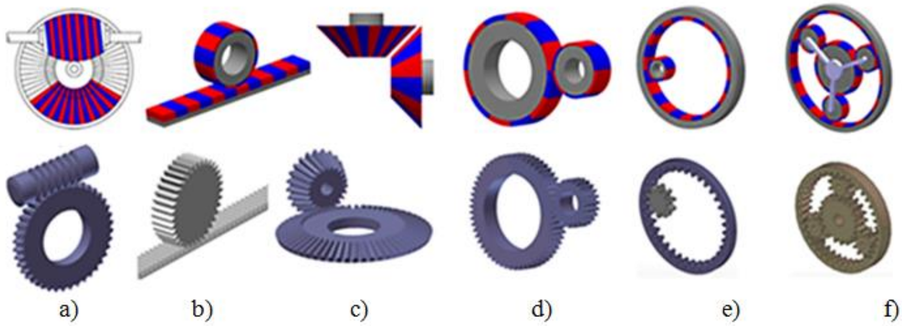


Figure 3 Comparative display of magnetic and mechanical gears:
a) worm gear, b) rack and pinion gear, c) bevel gear, d) external spur gear, e) internal spur gear, f) planetary gear [1]

In addition to these transmissions, there are also gears of more complex shape, such as a magnetic gear with helical teeth, worm gear and magnetic gear with skew shafts. These gears were suggested by Tsurumoto and Kikuchi, and their construction is described in detail in [9, 10, 4]. The hyperboloid gear has also been described in [15], with radial magnetization and hyperboloid north and south pole. The converted magnetic gears also include the magnetic planetary gears and variators. The torque, which is transmitted by a planetary gear, depends on the number of satellites. It can be increased with increasing number of satellites, but then the moment of inertia increases as well. The good side of these gears is that they have a high transmission ratio, high torque density, and three modes. The bad side of these gears is that the complexity of the gear structure increases with the increase of the number of satellites. The development of magnetic planetary gear is described with more details in [16, 17], also the gear analysis has been performed, and their application in devices with variable inertia has been described in [18].

Field-modulated magnetic gears are also called flux guided magnetic gears. With previously described type of the gears, the gears have a very short distance, so that the magnetic flux travels from one gear, through the air, to the second gear. Unlike them, there is a part made of iron, in field-modulated magnetic gears, which leads the flux from one gear to another. There are a large number of patents of the field-modulated magnetic gears. The principle of their work is based on the use of ferromagnetic materials for magnetic field modulation. These gears mainly consist of two rotors and the modulator. These gears include: linear concentric magnetic gear, axial magnetic gear and coaxial magnetic gear [1].

Linear magnetic gear is described in [19, 20] and it is shown in Figure 4 a). It has a tubular shape and its working principle is based on the change of the magnetic field produced by two movers with permanent magnets. The ferromagnetic parts, used for modulation of the magnetic field, are placed among them.

Axial magnetic gear is proposed in [21], and one of the gears of this type is shown in Figure 4 b). This gear concept is used when isolation between input and output shaft is necessary. Most often the mover of lower speed is made of silicon steel strip.

Coaxial magnet gear (CMG) is shown in Figure 4 c). It consists of the outer and inner rotor, and the modulator, which is situated between them. Modulator is composed of a cage, on which there are parts of a ferromagnetic material. Ferromagnetic material provides modulation (changing) of the magnetic field. This concept of transmission is patented by

Martin [22], however, its performances, especially high magnetic density, are more discussed in the papers [23, 24]. The inner rotor is usually the rotor of the higher speed rotation, and outer rotor is the rotor of the lower speed rotation.

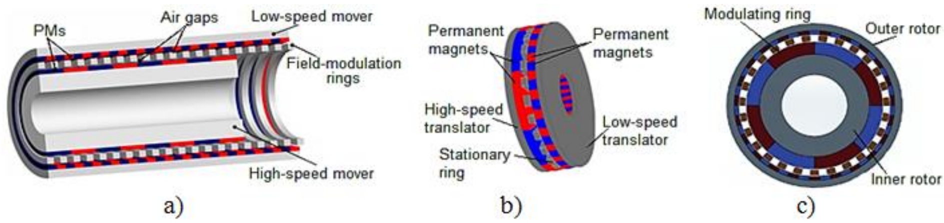


Figure 4 Field-modulated magnetic gears a) Linear magnetic gear [25], b) Axial magnetic gear [21], c) Coaxial magnetic gear (CMG) [23]

Comparative characteristics of mechanical and magnetic gears are given in Table 1. Some of the advantages of magnetic gears are that there are no noise and vibrations, no contact, so therefore, there is no need to use a lubricant. In certain case, the magnetic gears can transmit higher torques than the mechanical gear transmissions. In some concepts, the magnetic transmissions can be physically separated, so that, for example, they can be used in the food and chemical industries. At the overload of these gears, they would not be damaged, but it would come to gear slipping.

Table 1 Gear ratios and densities of torque for mechanical and magnetic gears [23]

Gear type	Transmission rate	Torque density [kNm/m^3]
Mechanical spur gear	1.4–28000	100–200
Multielement MG	24 : 1	3.96
Involute MG	3 : 1	1.7
Magnetic worm gear	33 : 1	0.74
Magnetic skew gear	1.7 : 1	0.15
Parallel-axis MG	4 : 1	11.6
Perpendicular-axis	1 : 1	3
Magnetic torque coupler	1 : 1	51.9
MPG	3 : 1	97.3

4. APPLICATION OF MAGNETIC GEARS

Since nowadays, the goal is to minimize environmental pollution and use the renewable energy sources, the interest for magnetic gears increases. These gears are not lubricated, there is no risk of lubricant pouring out into eg. the water. This is a very good side of these gears, especially in terms of environmental protection.

Linear, planetary, and even coaxial magnetic gears can be used in hybrid vehicles [11, 12, 13]. Figure 5 presents the model of a linear gear used in vehicles [23].

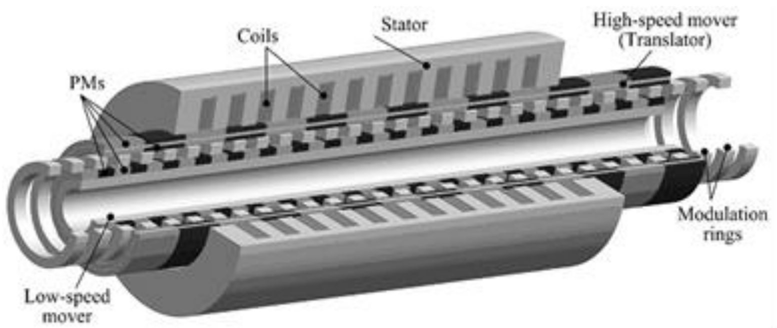


Figure 5 Linear magnetic gear in vehicles [12]

The company Magnomatics has managed to combine the magnetic gears with stator windings, thus getting Pseudo Direct Drive (PDD). PDD represents the replacement of motor and reducer and it can be used in all cases where conventional motor and reducer are used. One PDD is shown in Figure 6 [14].

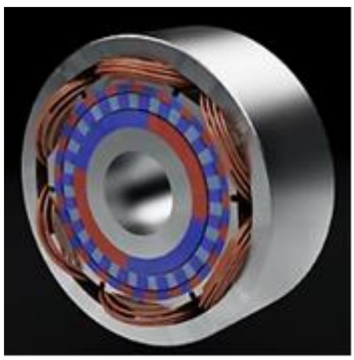
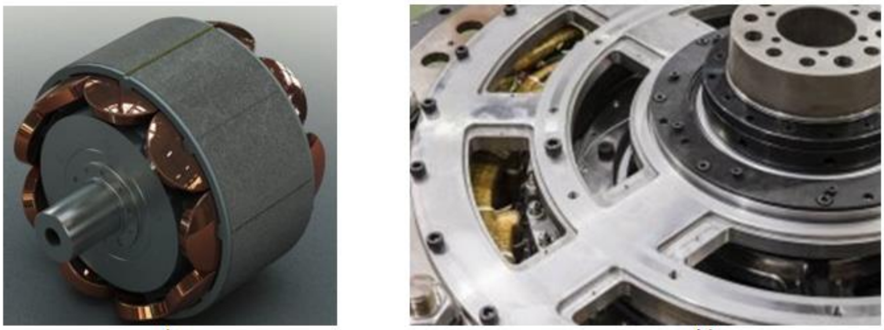


Figure 6 Pseudo Direct Drive (PDD) [14]

PDD may be applied in oil and gas industries, aeronautics (Figure 7 a)), as well as in maritime industry (Figure 7 b)) [14].



a) b)

Figure 7 a) PDD used in aerospace, b) PDD used in marine propulsion [14]

The Magnomatics Company has developed MAGSPLIT for hybrid vehicles (Figure 8), used for speed variation, which is a substitute for conventional ECVT systems for hybrid vehicles [14].

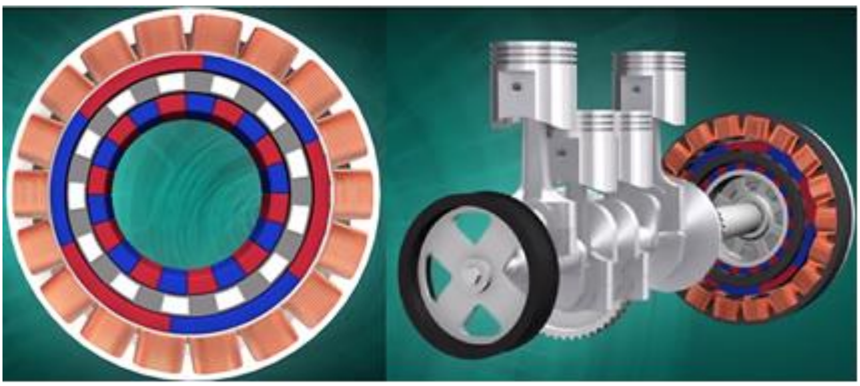


Figure 8 MAGSPLIT [14]

Linni Jian in [26] has given the design and analysis of magnetic motor for electric vehicles. A Halbach array of permanent magnets was used in magnetic gear of this motor. The appearance of the gear and the motor, built into the wheel of the vehicle, is shown in Figure 9.

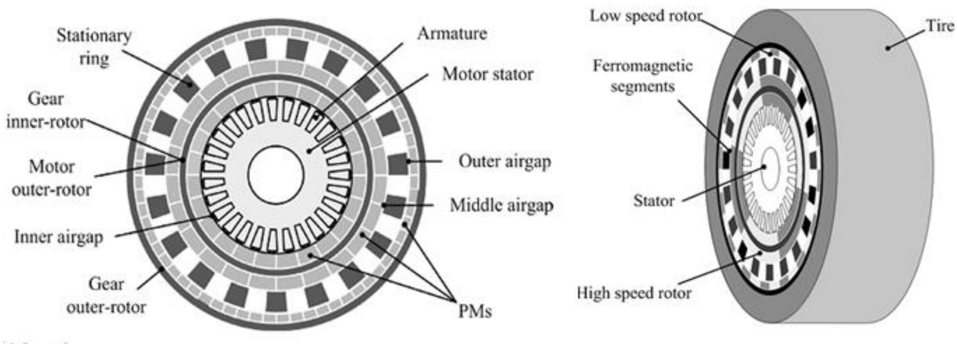


Figure 9 Halbach magnetic geared permanent magnet Motor [26]

The Ricardo Company has patented its mechanism with magnetic gears and magnetic couplings, as it is shown in Figure 10 a). This company has also developed Kinergy flywheel system, which is very compact, and it is shown in Figure 10 b). Flywheels are particularly good for vehicles which often brake, such as, cars, trucks, trains, trams, buses, machines for material handling, such as cranes and elevators, and even vans for delivery [27].

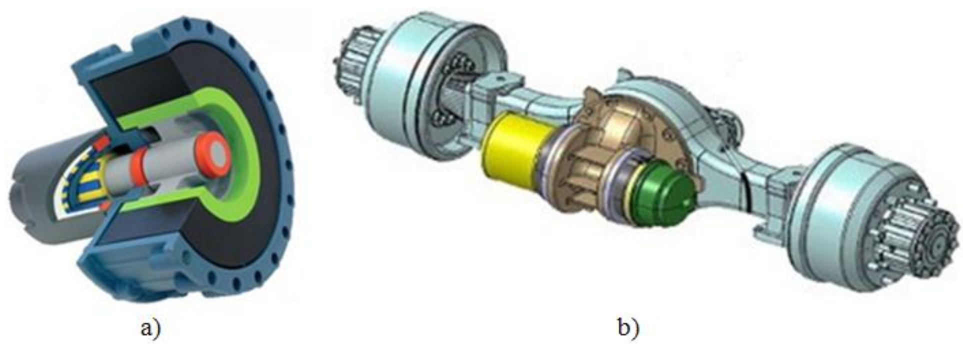


Figure 10 a) Ricardo's flywheel, b) Kinergy flywheel system integrated into a rear axle assembly [27]

Figure 11 a) shows the high efficiency excavator (HFX), where the new type of the flywheel, by the Ricardo Company with the name Ricardo TorqStor, is applied (Figure 11 b)).

a)

b)

Figure 11 a) High Efficiency Excavator, b) TorqStor [28]

The Ricardo Company, in cooperation with companies Torotrak, Optare, and Allison, developed Flybus Project that proved to be very good, because by using the flywheel while driving the bus, the emission of harmful gases decreases, fuel costs are reduced, as well as the brake wear [28]. Application of the flywheel within Flybus Project is shown in Figure 12.

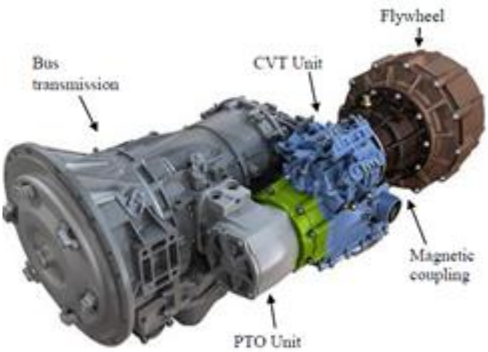
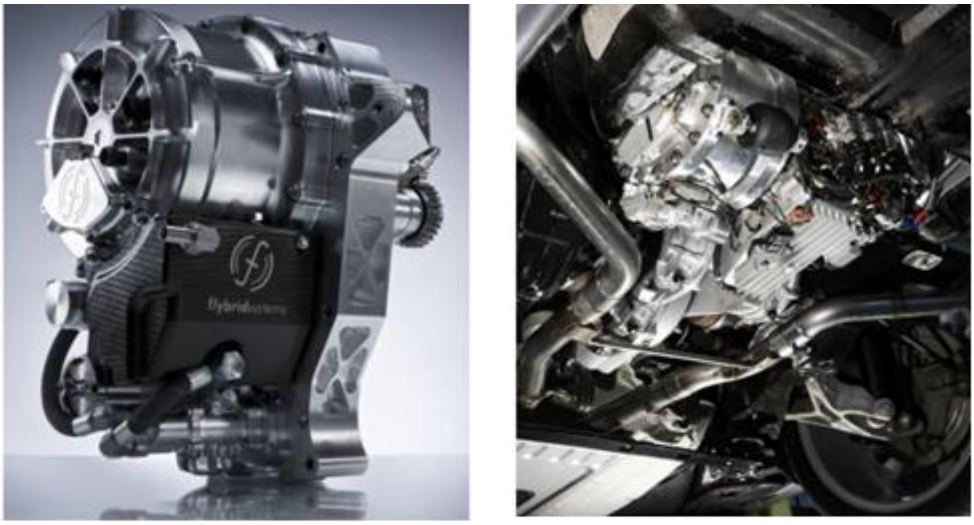


Figure 12 Application of flywheel in Flybus project [28]

Flybrid was developed within the Torotrak Groups and in cooperation with Ricardo Company (Figure 13 a)). The Flybird was developed for use in Formula 1. In June 2011, the new Clutched Flywheel Transmission (CFT) based system raced in the Le Mans 24-hour race and thus, had driven the first hybrid car that competed in this race. CFT is suitable for passenger cars as well. Figure 13 b) shows the use of Flybride flywheel with Jaguar test car [28].



a) *b)*

Figure 13 a) Clutched Flywheel Transmission, b) Flybrid flywheel in Jaguar test car [28]

Ricardo, Artemis Intelligent Power and Bombardier Transportation under the DDFlyTrain project examined the impact of using high speed flywheel energy storage technology on DMU (Diesel Multiple Unit) trains. The hybrid solution of this project is based on the use of high efficiency Artemis Digital Displacement hydraulic pump-motor transmission and Ricardo's TorqStor high-speed flywheel energy storage technology. Figure 14 shows TorqStor high-speed flywheel used in DDFlyTrain Project.

Figure 14 Flywheel used in DDFlyTrain project [28]

General Motors has applied the permanent magnet motor in its model Chevrolet Spark EV, as shown in Figure 15.

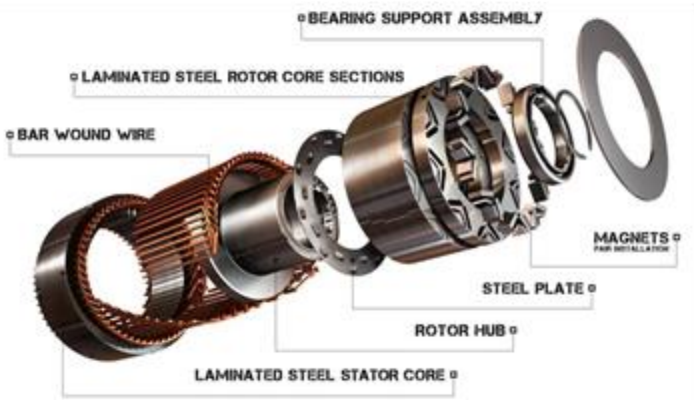


Figure 15 GM's permanent magnet EV motor [29]

In [30], a mechanical planetary gear of hybrid vehicles is replaced with magnetic planetary gear. The solution of such a magnetic planetary gear is given in Figure 16, where the generator, marked the MG1 and MG2, is a permanent magnet synchronous machine.

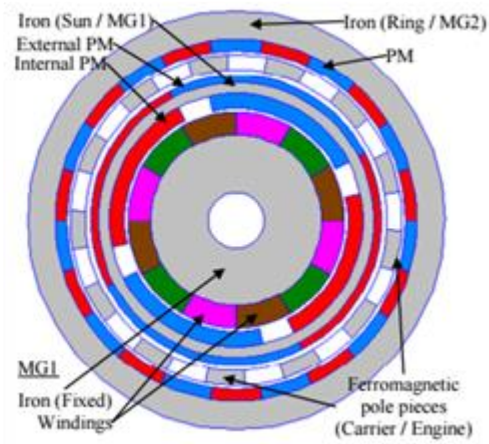


Figure 16 Magnetic planetary gear in hybrid vehicles [30]

The use of magnets in motors is given in [31]. Permanent magnet starter (PMGR-permanent magnet gear reduction starter) is a smaller in size, of simpler construction and it is less heated compared to conventional starters. Such a starter is shown in Figure 17. The magnetic starter uses 4 or 6 pairs of magnets instead of coils.

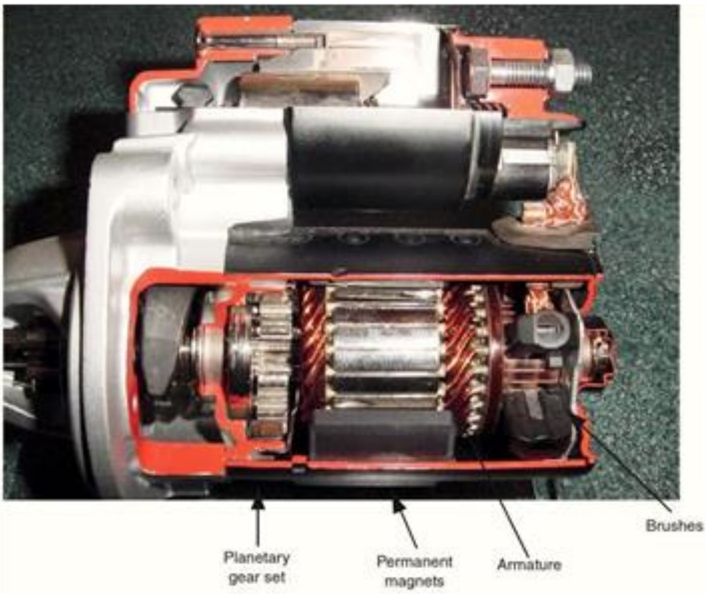


Figure 17 PMGR starter [31]

Magnetic transmissions are also used in spacecraft. One such prototype is shown in Figure 18 [32].

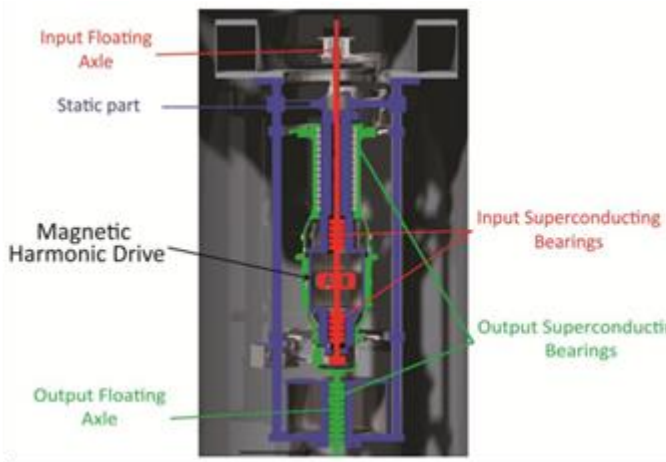


Figure 18 Magnetic transmission in aerospace [13]

A newer type of magnetic gears is magnetic cyclo gears. These gears, so far, are in the testing phase. The testing of the gears for use in hybrid vehicles is performed in [18, 32, 33].

These are just some of the examples of application of magnetic gears with means of transport. In the future, this application will be even greater, both in vehicles and in industry in general.

5. CONCLUSIONS

Nowadays, when the environmental pollution is the global problem, the aim is to find technologies whose use would reduce environmental pollution, so that the magnetic gears become significant in that way. The most importance is given to the use of magnetic gears in vehicles and means of transport. By combining magnetic gear with stator with electrical windings, the Magnomatics Company has thereby obtained Pseudo Direct Drive (PDD), which is the replacement of the motor and reducer and it can be used wherever the conventional motor and reducer are used. Flywheels in combination with magnetic gears are a new way to reduce fuel consumption in vehicles. The thing that with magnetic gears there are less or even no damage, that they do not create the noise and that they do not need to be lubricated, goes in favour of more frequent use of these gears. Considering that this is a new type of gears, it can be assumed that these advantages will affect, in the future, the more increasing use of magnetic gears. Most, if not all, kitchen appliances will have these gears, each hot drink in a cafe or a dish prepared at home will be obtained with the help of magnetic gears. Buses, trains, light and heavy trucks, taxis and private cars will move with the help of magnetic gears. All this will help to preserve the environment and improve the quality of life.

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REGULATIONS ON ROAD VEHICLE NOISE – TRENDS AND FUTURE ACTIVITIES

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UDC:629;534.292

ABSTRACT: Problem of vehicle noise has been observed since the appearance of the larger number of vehicles on the roads. Drivers and passengers are exposed to constant noise and vibration originating from their own vehicles and all other vehicles participating in traffic. This paper reviews development of regulations that impose limits for vehicle noise. Chronological development of vehicle noise regulations is presented in order to observe trends in corresponding noise limits and requirements. Required future activities in formulation of new vehicle noise regulations based on vehicle users' demands, developments and trends in automotive industry and requisites for vehicle weight reduction and cutting the costs of vehicle production are analysed in the paper.

KEY WORDS: vehicle, noise, regulations, standards, limits

PROPISI O BUCI DRUMSKIH VOZILA – TRENDOVI I BUDUĆE AKTIVNOSTI

REZIME: Problem buke vozila je praćen još od pojave većeg broja vozila na putevima. Vozači i putnici su izloženi konstantnoj buci i vibracijama koje potiču od sopstvenih vozila. Uz to, okruženje vozila sadrži buku svih ostalih vozila koja učestvuju u saobraćaju. Ovaj rad prikazuje pregled razvoja međunarodnih, regionalnih i nacionalnih propisa koji nameću dozvoljene granice spoljašnje i unutrašnje buke vozila. Prikazan je hronološki razvoj propisa u vezi unutrašnje i spoljašnje buke vozila da bi se uočili trendovi granica buke i odgovarajućih zahteva. Osim toga, analizirane su zahtevane buduće aktivnosti u vezi formulacije novih propisa o buci vozila zasnovane na zahtevima korisnika vozila, razvoju i trendovima u automobilskoj industriji i zahtevima u vezi smanjenja težine vozila i troškova proizvodnje vozila.

KLJUČNE REČI: vozilo, buka, propisi, standardi, dozvoljene vrednosti

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1. INTRODUCTION

It is universally acknowledged that noise is not only a huge ecological problem, but it represents an unpredictable danger to human health. This problem has been existing since forming of the huge cities and occurrence of the large number of engine operated vehicles on the city streets and roads. Thus, it is no surprise that only after three decades of existence of motorized transport, the British Government had introduced legislation to control the road vehicle noise, by a simple act, known as "The Motor Cars (Excessive Noise) Regulations, No. 416", passed in 1929. This act, adopted before the invention of any means of measuring noise, had authorized the police officers and courts to decide if the vehicle was too noisy [1].

Motor vehicle is a complex source of noise emission, made by equipping the vehicle with (internal combustion) engine. All surfaces of the vehicle's engine and chassis generate vibrations and sound waves, which are perceived as noise. Vehicle passengers hear the sum of all contributions from airborne noise and structure borne noise carried to the vehicle interior, joined by contributions from aerodynamic noise and tire rolling noise. In most cases, the passenger cannot distinguish different noise sources inside the vehicle. It can only be done by using corresponding measurement technique. However, drivers and passengers are not only exposed to noise originating from their own vehicles. Their environment also contains noise from all other vehicles participating in traffic.

Noise contributes to disorders of the cardiovascular, nervous and digestive system of the driver. It also has an adverse effect on the nervous system and induces stress and increased blood pressure. Excessive traffic noise damages driver's hearing and health. It frequently exceeds limit values set for occupational noise. This is particularly important for health of professional drivers, such as bus and truck drivers, who experience increased stress levels from the traffic and from their working schedules [2].

The European Parliament and the Council of Europe have adopted "Directive 2002/49/EC of the European Parliament and of the Council of 25 June 2002 relating to the assessment and management of environmental noise - Declaration by the Commission in the Conciliation Committee on the Directive relating to the assessment and management of environmental noise" in 2002. This Directive is also known as „END - Environmental Noise Directive", and it applies to environmental noise to which humans are exposed in urban and rural areas. Its goal is "to define a common approach intended to avoid, prevent or reduce on a prioritised basis the harmful effects, including annoyance, due to exposure to

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environmental noise“ [3]. In addition, END has a goal of providing a basis for developing community measures to reduce noise emitted by the major sources, one of them, in particular, being road vehicles.

Road traffic noise is the most prevalent environmental noise source in Europe. Estimations show that the overall number of people exposed to road traffic noise inside and outside urban areas amounts to around 24 % of the total European population. This means that around 125 million people are likely to be exposed to threshold levels of road traffic noise according to the Environmental Noise Directive (END) 2002/49/EC. The threshold levels used for noise mapping and action planning by the END are 55 dB for the day-evening-night noise indicator, Lden, and 50 dB for the night-time noise indicator, Lnight [4, 5].

Road traffic noise emissions can be reduced at a source, via measures relating to vehicles, tyres, road surfaces and traffic management, or by reducing the exposure of people by means of anti-propagation or insulation measures. Most European Union (EU) regulations focus on mitigating noise at the source, such as: establishing limits for the noise of vehicle engines and exhausts, promotion of quieter tyres and development of low-noise road surfaces. Low-noise road surfaces have considerable potential to cut road noise and are complementary to technical measures that reduce engine, exhaust and tyre noise from passenger cars and larger vehicles [5].

In recent years, the requirements relating to the acoustics of the vehicle has increased, which is, on one hand, caused by the increase in user demands, and on the other hand, by development and trends in the automotive industry. Thereby, reducing vehicle weight and costs have increasing importance. However, since there are requirements to achieve greater engine power, the price factor and legislation on vehicle recycling, it is necessary to find a compromise, primarily between weight and acoustic comfort, power, price and regulations.

Today, the acoustics in the passenger compartment is one of the most important performance of vehicles. Noise inside the vehicle has a central role and it suppresses the effects of other vehicle characteristics. Thus, when the noise is unpleasant, the impression of a quality vehicle is lost. Automotive manufactures are paying special attention to reduction of vehicle noise. For example, over several decades, Japan’s automakers have introduced new technologies into their products to reduce vehicle noise. Because of those efforts, the vehicles they manufacture today are extremely quiet. Compared to the levels in 1971, when regulations in this area were first introduced in Japan, heavy-truck noise has been reduced by 92%, passenger car noise by 83% and motorcycle noise by 95% [6].

Over the years, vehicle interior noise is significantly reduced in response to customer expectations. In the last 40 years, the greatest improvements were observed in reducing differences in the levels of internal noise between family and luxury vehicles. Unlike external noise, it is believed that the existence of internal noise is advisable to make an impression on the character of the vehicle and as indication of the speed of the vehicle. Some modern luxury, electric and hybrid vehicles have even gone below the ideal noise limits. In fact, they are too quiet.

Although there was knowledge that prolonged exposure to noise causes hearing loss, there have been no proposals of standards in relation to noise exposure limits until 1950s. The US Air Force approved the first standard on noise exposure in the United States in 1956. Research bodies and committees for adoption of standards had discussed the issues of noise for more than a decade, before the exposure limits to noise have entered the legislature [7].

International Organization for Standardization (ISO) and its Technical Committee 43 (ISO/TC 43) are dealing with global acoustics problems, some of which are related to vehicle noise problems. United Nations Economic Commission for Europe (UNECE) has also published a series of regulations on vehicle noise, starting from Directive 70/157/EEC in 1970.

Institute for standardization of Serbia (ISS), as a national body for standardization, has adopted a set of standards on noise emitted by motor vehicles, which are identical to corresponding regional standards in European Union (EN standards), European standards based on international standards (EN ISO standards) or international standards (ISO standards). In addition, Serbian "Regulation on division of motor vehicles and trailers and technical requirements for vehicles in road traffic" defines the limits for allowed exterior noise emitted by motor vehicles.

2. INTERNATIONAL REGULATIONS ON ROAD VEHICLE NOISE

The most important international organizations that publish standards on measurement and analysis of noise are International Electro technical Commission (IEC) and International organization for standardization (ISO). IEC is responsible for design of instruments for noise measurement noise, while ISO, as the holder of standardization, is competent in the fields of measurement techniques, experimental conditions, measurement parameters and limits for the measurement results.

2.1 ISO standards

International organization for standardization (ISO) is the worldwide federation of national bodies for standardization. The preparation of international standards is conducted through numerous technical committees. ISO closely cooperates with International electrotechical commission on all problems of standardization in the area of electrotechical engineering.

ISO and its Technical committee 43 - Acoustics, Sub-committee 1 - Noise (ISO/TC 43/SC 1) deal with global problems of noise in 111 standards published and 23 standards currently under development. The ISO/TC 43/SC 1 standards that are related directly to noise emitted by road vehicles are shortly described in Table 1.

The following ISO/TC 43/SC 1 standards deal with the influence of road surfaces on traffic noise:

- ISO 10844:2014 - Acoustics - Specification of test tracks for measuring noise emitted by road vehicles and their tyres
- ISO 11819-1:1997 - Acoustics - Measurement of the influence of road surfaces on traffic noise - Part 1: Statistical Pass-By method
- ISO/PAS 11819-4:2013 - Acoustics - Method for measuring the influence of road surfaces on traffic noise - Part 4: SPB method using backing board
- ISO 13472-1:2002 - Acoustics - Measurement of sound absorption properties of road surfaces in situ - Part 1: Extended surface method and
- ISO 13472-2:2010 - Acoustics - Measurement of sound absorption properties of road surfaces in situ - Part 2: Spot method for reflective surfaces.

Table 1: ISO/TC 43/SC 1 standards directly related to noise emitted by road vehicles

ISO/TC 43/SC 1 standard	Brief description
ISO 362-1:2015 - Measurement of noise emitted by accelerating road vehicles - Engineering method - Part 1: M and N categories	- specifies an engineering method for measuring noise of road vehicles of categories M and N under typical urban traffic conditions
ISO 362-2:2009 - Measurement of noise emitted by accelerating road vehicles - Engineering method - Part 2: L category	- specifies an engineering method for measuring noise of road vehicles of categories L3, L4 and L5 under typical urban traffic conditions
ISO 362-3:2016 - Measurement of noise emitted by accelerating road vehicles - Engineering method - Part 3: Indoor testing M and N categories	- specifies an engineering method for measuring noise of road vehicles of categories M and N by using a semi anechoic chamber
ISO 5128:1980 - Acoustics - Measurement of noise inside motor vehicles	- specifies the conditions for obtaining reproducible and comparable data of noise levels and spectra inside road vehicles (excluding agricultural tractors and field machinery)
ISO 5130:2007 - Acoustics - Measurements of sound pressure level emitted by stationary road vehicles	- specifies conditions for measuring the exterior sound pressure levels from stationary road vehicles, with continuous measurement of the sound pressure level over a range of engine speeds; - applies only to road vehicles of categories L, M and N equipped with internal combustion engines
ISO 9645:1990 - Acoustics - Measurement of noise emitted by two-wheeled mopeds in motion - Engineering method	- specifies an engineering method for measuring noise of two-wheeled mopeds in motion in urban traffic flow of irregular character, with full use of the available engine power
ISO 16254:2016 - Acoustics - Measurement of sound emitted by road vehicles of category M and N at standstill and low speed operation - Engineering method	- specifies an engineering method for measuring the sound emitted by M and N category road vehicles' principal sound sources in stationary and low speed vehicle operating conditions relevant for pedestrian safety; - derived from ISO 362-1

Some of the standards from this category, also related to influence of road surfaces on traffic noise are currently under development:

- ISO/DIS 11819-2.2 - Acoustics - Measurement of the influence of road surfaces on traffic noise - Part 2: The close-proximity method and
- ISO/DTS 11819-3 - Acoustics - Measurement of the influence of road surfaces on traffic noise - Part 3: Reference tyres.

The tyre/road noise is the subject of one standard published by ISO/TC 43/SC 1:

- ISO/CD 13471-1 Acoustics -- Temperature influence on tyre/road noise measurement -- Part 1: Correction for temperature when testing with the CPX method while ISO Technical committee 31 - Tyres, rims and valves (ISO/TC 31) has one published standard related to tyre/road noise:
- ISO 13325:2003 - Tyres - Coast-by methods for measurement of tyre-to-road sound emission

and one standard in development stage:

- ISO/NP 20908 - Tyre noise test - Methods of drum.

All mentioned ISO standards dealing with road vehicle noise provide necessary information on measurement techniques and equipment to be applied, experimental conditions to be met, measurement parameters to be taken into account and the limits for the measurement results.

2.2 UNECE regulations

United Nation's Economic Commission for Europe (UNECE) has published a series of 137 regulations as addenda to the 1958 Agreement ("Agreement concerning the adoption of uniform technical prescriptions for wheeled vehicles, equipment and parts which can be fitted and/or be used on wheeled vehicles and the conditions for reciprocal recognition of approvals granted on the basis of these prescriptions"). The following UNECE regulations are related to road vehicle noise:

- Regulation No. 9 (UN/ECE R9) – Uniform provisions concerning the approval of category L2, L4 and L5 vehicles with regard to noise
- Regulation No. 41 (UN/ECE R41) - Uniform provisions concerning the approval of motor cycles with regard to noise
- Regulation No. 51 (UN/ECE R51) - Uniform provisions concerning the approval of motor vehicles having at least four wheels with regard to their sound emissions
- Regulation No. 63 (UN/ECE R63) - Uniform provisions concerning the approval of two-wheeled mopeds with regard to noise
- Regulation No. 117 (UN/ECE R117) - Uniform provisions concerning the approval of tyres with regard to rolling sound emissions and to adhesion on wet surfaces and/or to rolling resistance.

After a 15-year-long discussion, UNECE Working party on noise (GRB) has finally reached agreement on the third series of amendments to regulation UN/ECE R51 (UN/ECE R51.03) in September 2014. Regulation UN/ECE R51.03 was adopted by the UN World forum for harmonization of vehicle regulations (WP.29) in June 2015. It will enter into force in three phases, starting from 20 January 2016.

Regulation UN/ECE R51.03 has introduced a transition from emphasis on powertrain to total vehicle test (including the tyres). It contains the most recent decibel limit values for all types of road vehicles with at least four wheels, presented in Table 2 [8].

For vehicles with low and medium power engines, the limit values are already lower than 74 dB(A), which is a long standing limit. In later phases, in 2020 and 2024, these limits will be decreased considerably. New measurement procedures and considerably reduced pass-by-noise limit values will be, certainly, a great challenge to automotive industry in the world.

Table 2: Limit values for pass-by noise of road vehicles with at least four wheels according to GRB [8]

Vehicle category	Vehicle used for the carriage of passengers	Limit values expressed in dB(A)		
		Phase 1 applicable for new vehicle types from 1 July 2016	Phase 2 applicable for new vehicle type from 1 July 2020 and for first registration from 1 July 2022	Phase 3 applicable for new vehicle type from 1 July 2024 and for first registration from 1 July 2026
M1	power to mass ratio ≤ 120 kW/1000 kg	72(1)	70(1)	68(1)
M1	120 kW/1000 kg < power to mass ratio ≤ 160 kW/1000 kg	73	71	69
M1	160 kW/1 000 kg < power to mass ratio	75	73	71
M1	power to mass ratio > 200 kW/1 000 kg number of seats ≤ 4 R point of driver seat ≤ 450 mm from the ground	75	74	72
M2	mass ≤ 2 500 kg	72	70	69
M2	2500 kg < mass ≤ 3 500 kg	74	72	71
M2	3500 kg < mass ≤ 5 000 kg; rated engine power ≤ 135 kW	75	73	72
M2	3500 kg < mass ≤ 5 000 kg; rated engine power > 135 kW	75	74	72
M3	rated engine power ≤ 150 kW	76	74	73(2)
M3	150 kW <rated engine power ≤ 250 kW	78	77	76(2)
M3	rated engine power > 250 kW	80	78	77(2)
Vehicle category	Vehicle used for the carriage of goods	Phase 1 applicable for new vehicle types from 1 July 2016	Phase 2 applicable for new vehicle type from 1 July 2020 and for first registration	Phase 3 applicable for new vehicle type from 1 July 2024 and for first registration

			from 1 July 2022	from 1 July 2026
N1	mass ≤ 2 500 kg	72	71	69
	2 500 kg < mass ≤ 3 500 kg	74	73	71
N2	rated engine power ≤ 135 kW	77	75(2)	74(2)
	rated engine power > 135 kW	78	76(2)	75(2)
N3	rated engine power ≤ 150 kW	79	77	76(2)
	150 kW < rated engine power ≤ 250 kW	81	79	77(2)
	rated engine power > 250 kW	82	81	79(2)

(1) M1 vehicles derived from N1 vehicles: M1 vehicles with an R point > 850 mm from the ground and a total permissible laden mass more than 2 500 kg have to fulfil the limit values of N1 (2 500 kg < mass ≤ 3 500 kg).

(2) + two years for new vehicle type and + one year for new vehicles registration

Problem with „silent vehicles“

Noise emitted by road vehicle is used to detect presence of the vehicle, to assess its speed or decide whether the vehicle is accelerating or decelerating. However, hybrid and electrical vehicles do not emit significant levels of noise and they may be a safety risk for blind or visually impaired people, pedestrians or cyclists. The expanding share of these vehicles on today's market has brought the danger of their quietness while running at low speed.

The problem of so-called "silent vehicles" is addressed by a new regulation adopted by the UNECE World Forum for Harmonization of Vehicle Regulations (WP.29) – „Regulation on Quiet Road Transport Vehicles (QRTV)". This Regulation requires implementation of acoustic warning devices on hybrid and electric vehicles. The goal of the regulation is to minimize the risk posed by silent vehicles [9].

The new Regulation demands that quiet vehicles should be equipped with an Acoustic Vehicle Alerting System (AVAS) to create artificial noise in the speed range from 0 to 20 km/h. The tyre/road noise and wind noise are audible at speeds above 20 km/h, so there is no need for artificial noise in this range of vehicle speed. The Regulation introduces the minimum AVAS sound pressure levels and spectrum and frequency shift, depending on the vehicle's speed. When the car's speed increases, the sound becomes louder so that pedestrians can audibly judge the speed. At this stage, the Regulation covers only acoustic measures to overcome the concerns of reduced audible signals from electrified vehicles. In the future, the Regulation should encompass other, non-acoustic measures, such as pedestrian detection systems within the vehicle [10].

2.3 European regulations

Activities to be implemented throughout Europe in order to reduce environmental noise have a different priority compared to ecological problems such as air and water pollution, often because it was thought that such issues are best handled at national or local level. Since information on the impact of noise on human health are increasingly available, there is more pronounced need for a higher level of protection of EU citizens against noise through a wider framework of measures in all of Europe.

The European Union (EU) and the European free trade association (EFTA) have officially recognized the European committee for standardization (CEN) as one of three European standardization organizations (together with CENELEC - European committee for electrotechnical standardization and ETSI - European telecommunications standards institute) responsible for development of European voluntary standards. CEN brings together the national standardization bodies of 33 European countries and supports standardization activities in relation to a wide range of fields, including transport. European standards (ENs) approved by CEN and CENELEC are accepted and recognized in all of member countries. However, most standards related to road transport are defined at global (international) level, so CEN coordinates its activities in this field with activities of ISO [11]. Recent standardization activities of CEN do not include projects related to road vehicle noise.

In Europe, control of exterior noise emitted by road vehicles is conducted through procedures of the type-approval of the vehicle. Each new type of vehicle on the market must fulfil demands published in legislation. In 1970, the former European Economic Community adopted Directive 70/157/EEC, which has introduced permissible noise levels for all motor vehicles with at least four wheels travelling with maximum speed of more than 25 kmh^{-1} (cars, trucks, buses). It has been adjusted by the laws of the member states concerning the permissible noise levels and exhaust systems of motor vehicle and has undergone several amendments in the field of noise limits and measuring methods:

- 77/212/EEC - change in vehicle categories and introduction of decreased noise limits
- 81/334/EEC - amendments to the method of measuring the noise of moving and stationary vehicles in order to get them closer to the actual operating conditions
- 84/372/EEC - amendments to the method of measuring the noise emitted by high-performance vehicles and vehicles with automatic transmissions with manual adjustments in order to get them closer to the actual operating conditions
- 84/424/EEC - replacement of noise limit values by lower values for all categories of vehicles
- 92/97/EEC - comprehensive amendments by reduction of the noise level limits for all categories of vehicles and by improving the test method for vehicles with large engine power, because this type of vehicle is increasingly designed in such way that it has a higher power-to-mass (PTM) ratio of the vehicle and the curve representing the engine torque as a function of the engine speed was changed to produce a greater driving force at low engine speeds; new designs have increased the use of gear lever in urban traffic and have a major impact on the noise emitted by the mechanical parts of the vehicle as compared to road noise
- 2007/34/EC – introduction of a new test cycle, which gets demanded driving conditions nearer to actual driving conditions (as described in UN/ECE R51.02).

Regulation EU 540/2014 on the sound level of motor vehicles and of replacement silencing systems of the European Parliament and of the Council of Europe has repealed the Directive 70/157/EEC in 2014. Reason behind this event is in the fact that, despite the increased traffic, EU noise emission limits have not changed for more than 20 years. Thus, the European commission has proposed to reduce the noise produced by passenger cars, light commercial vehicles, buses, light trucks, coaches, and trucks in hope to reduce road vehicle noise by around 25%. The new regulation has introduced [12]:

- new test method that better reflects current driving behaviour
- lower noise limit values

- additional sound emission provisions (ASEP), which will be included in type-approval procedure as preventive requirements intended to cover driving conditions in real traffic, ensuring that the noise of a vehicle under street driving conditions does not significantly differ from vehicle noise when it is tested
- a specific Annex on minimum noise of electric and hybrid electric vehicles and
- noise labelling in order to foster competition with manufacturers displaying the sound level of each vehicle during sale.

To illustrate how noise limits have changed by European directives in last several decades, Figure 1 presents trends in pass-by-noise limit values for passenger vehicles, as they have been altered through years and expected future values. In the future, the limit values for M1 type of vehicles will be lowered in two steps of 2 dB(A) each.

For N3 types of vehicles with rated engine power below 250 kW, limits will be lowered by 2 dB(A) in two steps, while for N3 types of vehicles with rated engine power above 250 kW, the reduction will be 1 dB(A) for the first step and 2 dB(A) for the second step, Figure 2.

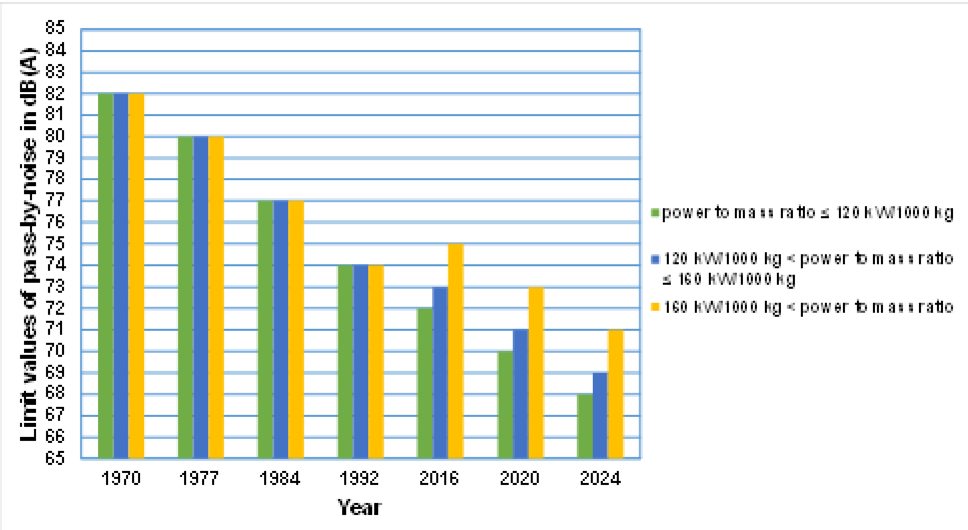

Figure 1 Trends in pass-by-noise limit values for M1 type of vehicles in European directives

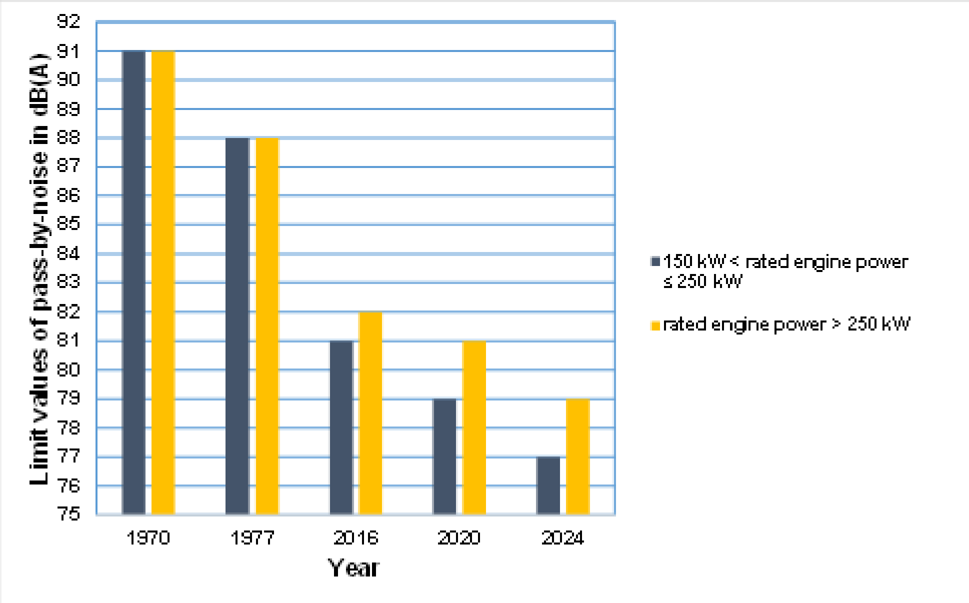

Figure 2 Trends in pass-by-noise limit values for N3 type of vehicles in European directives

3. ROAD VEHICLE NOISE IN SERBIAN REGULATIONS

Institute for standardization of Serbia (ISS), as a national body for standardization, has adopted a set of Serbian standards (SRPS) on noise emitted by motor vehicles, which are identical to corresponding European standards based on international standards (EN ISO standards) or international standards (ISO standards). The following SRPS standards are directly related to problems of road vehicle noise:

- SRPS EN ISO 11819-1:2012 - Acoustics - Measurement of the influence of road surfaces on traffic noise - Part 1: Statistical Pass-By method (ISO 11819-1:1997)
- SRPS ISO 362-1:2015 – Measurement of noise emitted by accelerating road vehicles - Engineering method - Part 1: M and N categories
- SRPS ISO 5128:2015- Acoustics - Measurement of noise inside motor vehicles.

Serbian “Regulation on classification of motor vehicles and trailers and technical requirements for vehicles in road traffic” [13] deals with problems of motor vehicle noise in its Article 78. According to this Article, the limit values of allowed exterior noise for each type of vehicle, measured in laboratory conditions, are presented in Table 3.

Table 3 Limit values of allowed exterior noise emitted by road vehicles in laboratory conditions [13]

Vehicle category	Limit value of noise in dB(A)
Two-wheeled vehicles	
L1	81
L3 with two-stroke engines with engine capacity not higher than 125 cm3	85
L3 with two-stroke engines with engine capacity higher than 125 cm3	87
L3 with four-stroke engines with engine capacity not higher than 125 cm3	85
L3 with four-stroke engines with engine capacity from 125 cm3 to 500 cm3	87
L3 with four-stroke engines with engine capacity higher than 500 cm3	89
Three-wheeled vehicles	
L2, L4, L5	88
Motor vehicles with at least four wheels	
M1, K5a, L6 and L7	87
M2 and N1	88
M3, N2 and N3 and with engine rated power not higher than 147 kW	92
M3, N2 and N3 and with engine rated power higher than 147 kW	95

Exterior noise is measured according to the method for measurement of noise of stationary vehicle. Articles of this Regulation do not apply to vehicles produced or registered for the first time before January 1st, 1972 and to military vehicles.

Another Serbian Regulation - "Regulation on technical and technical-exploitation requirements that must be met by trucks and busses conducting international public transport in road traffic" [14] sets the technical requirements regarding noise and pollutant emissions and technical-exploitation requirements regarding safety that must be met by trucks, trailers and buses, which conduct international public transport in road traffic. According to this Regulation, and consistent with provided Certificates of fulfilment of technical requirements in terms of noise and pollutant emissions, the heavy-duty vehicles are divided into the following categories:

- "Green"
- "Greener and safe"
- "EVRO III safe"
- "EVRO IV safe"
- "EVRO V safe"
- "EVRO EEV safe" and
- "EVRO VI safe".

Serbian „Low on safety and health at work" [15] states that, until regulations on general and specific safety and health measures are not set, measures for safety at work will be applied which are contained by „Regulation on measures and norms of protection at work against noise in work areas“ [16]. This Regulation sets the occupational noise thresholds in relation to the type of work. For physical work focused on precision and concentration with intermittent assessment and control of environment by hearing and for control of transport devices, the threshold limits are:

- 80 dB(A) for noise made by device operated by worker and
- 70 dB(A) for noise emitted by non-production sources (like street traffic).

Also, according to „The low on safety and health at work“, articles of “Regulation on occupational safety during motor vehicle maintenance and motor vehicle transport” may also be applied until regulations on general and specific safety and health measures are not set (if not in collision with the Low). This Regulation states that, during operation of engine, noise inside the vehicle dedicated to carry passengers and crew must not exceed 80 dB [17].

4. CONCLUSIONS

Noise is inevitable companion of accelerated technological development. In today’s society, there is a constant need to pay attention to noise protection, because noise is one of the most frequent ecological problems in the community. Road traffic noise, in particular, presents a very complex noise source, both in and out of urban areas. It is a product of effects of a number of factors: vehicle noise and driving practices, road structure, road surface quality, the traffic flow and factors of the roadside environment. Based on measurements of noise levels and traffic parameters and their analysis, it is noticed that the approach of individual analysis of each factor and assessment of their contribution to the total noise levels may lead to wrong conclusions. Thus, comprehensive measures must be introduced in order to address the multiple challenges involved in effective road traffic noise reduction.

Very important actions are taken on international level in order to decrease the traffic noise. Corresponding technical regulations and international standards are developed and adopted in this field. Most European regulations are focused on reducing the traffic noise at the source – by applying measures on newly produced vehicles. More and more strict limits are established for noise of vehicle engines and exhausts. Quieter types of vehicles are promoted and low-noise road surfaces are developed. There are some opinions that stricter vehicle noise standards are so cost-effective that 100 times more people can be protected from road noise for every Euro spent on development and production of quitter vehicles instead of on application of noise barriers and sound insulation.

Problem of road vehicle exterior noise should attract greater attention. It is necessary to monitor traffic noise levels emitted by each of vehicle categories, continually, during longer periods (couple of years) in order to take a stand about fulfilment of requirements and standards defined by authorized bodies. In addition, measures to be taken in addressing tire-road noise reduction and development of quiet road surfaces will play an important role in meeting the environmental standards in the future.

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