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INFLUENCE OF THE TREND OF MODERN VEHICLES MAXIMAL SPEED AND ACCELERATION INCREASING ON THE TRAFFIC SAFETY

Dragoljub Radonjić[1]*PhD, full professor*, ***Aleksandra Janković,*** *PhD, full professor*, ***Rajko Radonjić,*** *PhD, full professor*

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Summary

Speed, definitely, represents one of the most important exploitation parameters of the vehicle, as with its increase, travel duration is shortened, thus increasing the vehicle efficiency as a mean of transportation. On the other hand, increase of speed and acceleration demands better driver reflexes, increases the braking time, inertial force, as well as movement energy, which all in all affects the risk occurrence and the severity of consequences of traffic accidents. Therefore, there are harsh regulations regarding speed limit of the vehicles on public roads.

Tendency to increase the maximum speed and acceleration is present for contemporary vehicle producers, although it demands the enhancement of many characteristics: the drive aggregate, (more power, torque and dynamics), aerodynamics of the chassis, durability and reliability of vital parts and joints, which drastically increases the production costs.

This study represents the grade results of effect of speed and acceleration on the safety of traffic in characteristic movement regimes; rapid halt, overtaking a vehicle, driving in a column, which are derived through the usage of simulation modules. Based on these results, results of statistical analysis of maximum speed and acceleration increase of contemporary vehicles, as well as speed limits in specific countries, there is a conclusion derived explaining the plausibility of such tendency and certain recommendations are provided.

Key words: maximum vehicle speed, acceleration, traffic safety

UTICAJ TRENDA POVEĆANJA MAKSIMALNE BRZINE I UBRZANJA SAVREMENIH VOZILA NA BEZBEDNOST SAOBRAĆAJA

UDC: 621.43:656.052.48]:656.08

Rezime: Brzina predstavlja svakako, jedan od najznačajnih eksploatacionih parametara vozila čijim povećanjem se skraćuje vreme putovanja, a samim tim povećava efikasnost vozila kao saobraćajnog sredstva. S druge strane, povećanje brzine i ubrzanja vozila zahteva bržu reakciju vozača, povećava put kočenja, inercijalne sile, kao i energiju kretanja, što sve skupa utiče na povećanje rizika pojave i težinu posledica saobraćajnih nezgoda. Zbog toga

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su u svim zemljama sveta doneti oštri propisi o ograničenju maksimalne brzine kretanja vozila na javnim putevima.
Trend povećanja maksimalne brzine i ubrzanja je prisutan kod današnjih proizvođača vozila iako on zahteva poboljšanje mnogih karakteristika: pogonskog agregata (veća snaga, obrtni moment i dinamičnost), aerodinamičnosti školjke, čvrstoće i pouzdanosti vitalnih delova i sklopova, što bitno poskupljuje tehnološki proces.
U radu su prikazani rezultati ocene uticaja brzine kretanja i ubrzanja vozila na bezbednost saobraćaja u karakterističnim režimima kretanja: naglo zaustavljanje, preticanje, vožnja u koloni, koji su dobijeni korišćenjem simulacionih modela. Na bazi tih rezultata, rezultata statističke obrade trenda povećanja maksimalne brzine i ubrzanja savremenih vozila, kao i maksimalno dozvoljenih brzina u pojedinim zemljama, izveden je zaključak o opravdanosti takvog trenda i date određene preporuke.

Ključne reči: maksimalna brzina vozila, ubrzanje, bezbednost saobraćaja

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INTRODUCTION

Speed represents the most significant exploitation parameter of motor vehicles which can be used to most completely express their efficiency. The need to reduce the travel time and goods transport issued a demand – to increase the speed of vehicles. Therefore, the tendency to increase the maximum speed was always present, which reaches around 200km/h for passenger vehicles. On the other hand, maximum speed increase has – for a consequence – a number of negative effects:

- the reduction of traffic safety for vehicles, due to an increase of risk of traffic accidents,
- greater consequences in case of traffic accident, due to the increased kinetic energy of the vehicles,
- increase in fuel consumption and in emission of toxic materials,
- increasing the strength of the drive aggregate,
- construction changes of vital vehicle parts and joints, in order to increase their hardiness, functionality, and reliability.

The main and limiting factor of maximum speed increase is certainly its negative effect on traffic safety. Thus, law limits of maximum speed are induced, and its values depend on traffic conditions: residential zones, local and main roads, highways. Although the maximum speed limits differ, in most countries they stand at 120km/h on highways. Contemporary passenger vehicles have far higher maximum speed, which can be seen on a graph on *Figure 1*.

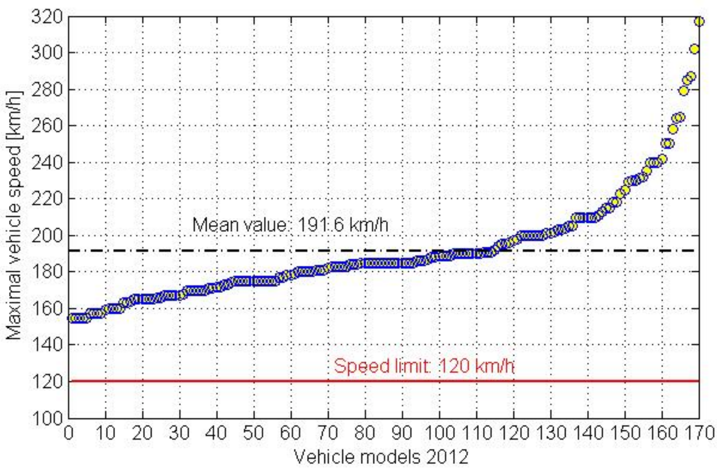

***Figure 1** Maximum speed of contemporary passenger vehicles (170 models from different manufacturers)*

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The condition shown by the graph on *Figure 1* indicates potential dangers regarding speeding, considering that the kinetic energy of the vehicle changes with the square of speed. In order to gain a more real evaluation of that energy's value, graph on *Figure 2* represents the comparative graph of the "Bofors" cannons of different caliber, with different masses and different projectile speeds, and of a vehicle weighting one ton, whose speed is 120 (MV120) and 200km/h (MV200). This comparison can be illustrated via concrete data that the energy of the vehicle MV200 equals energy of the 5 kg projectile, fired with initial speed of 800 m/s, which represents 70-100mm cannon caliber. Given facts support the attitude that the motor vehicle can be considered a weapon of murder with devastating power!

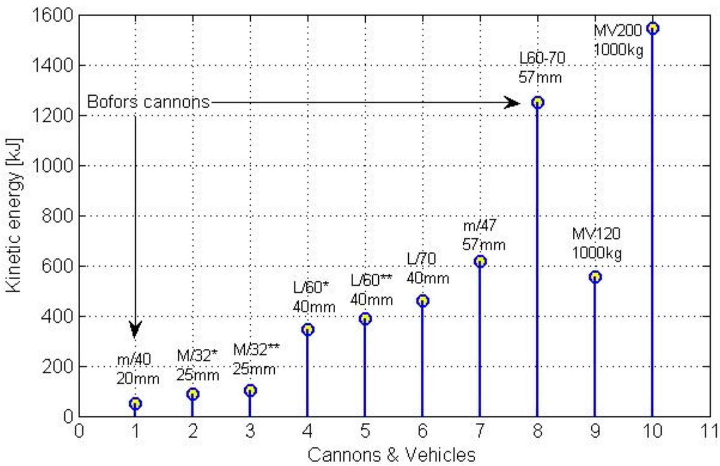

Figure 2 *Kinetic Energy of cannons and vehicles*

Due to before shown facts, main goals of this research are:

- research of the effect of vehicle speed on cause and severity of the traffic accident [1],
- determining a method for controlling and limiting the vehicle speed [2],
- research of the effect of vehicle speed on fuel consumption and toxic materials emission [3],

Research in this field, so far, did not have for a goal the evaluation of the maximum speed increase on demands placed during the project phase of the vehicle and its subsystems. Namely, the increase of maximum speed demands the change in engine performances (power, torque, maximum rpm, dynamics) transmission (number and layout of transmission degrees), vehicle itself (chassis aerodynamics, characteristics of pneumatics, mechanical hardiness and vital parts reliability). Fulfilling these demands increases the production costs of the vehicle. This study researches the tendency to increase the maximum speed in order to provide a conclusion regarding its requirements.

1. THE EFFECT OF SPEED IN THE CHARACTERISTIC REGIMES OF VEHICLE MOVEMENT

General characteristic of all vehicle movement in real regimes of exploitation is the change of speed caused by traffic flow. Based on statistical analysis of real regimes of the vehicle, it is possible to define a typical curve of speed changes during the exploitation (*Figure 3*).

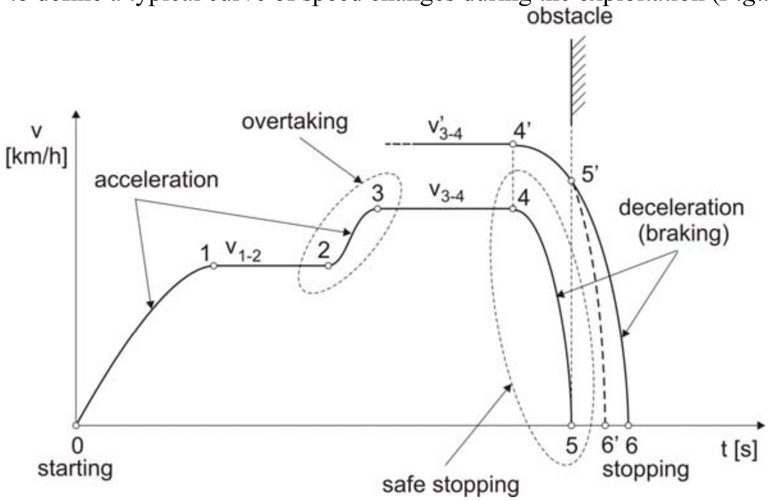

Figure 3 *Characteristic curve of speed changes during vehicle movement*

Of all regimes of the vehicle movement, highest risk comes, certainly, from maneuvers: overtaking (2÷3) and braking in case of the sudden appearance of another traffic participant or immobile obstruction on vehicle course(4÷5). Basic parameters which affect the safe conducting of these maneuvers, apart from driver reaction time and proper evaluation of the situation are: the intensity of vehicle acceleration (overtaking) and the efficiency of the braking process (safe stop).

However, from graph on *Figure 3* we can notice that the successfulness of these maneuvers is affected by constant values of speeds v_{1-2} i $v_{3-4.}$ Specifically, in the case of safe stop, with an increase in speed value from v_{3-4} to $v_{3-4.}$, under the same braking process efficiency, braking time is lengthened, which leads to an increase risk of traffic accident. On the other hand, increase in speed v_{3-4} leads to the increase of vehicle kinetic energy, leading to more severe consequences in the case of traffic accident.

1.1 Analysis of the effect of vehicle speed on dynamic processes in the case of traffic accident

The most basic way to prevent a traffic accident is to safely stop a vehicle before it comes into contact with an obstacle in its trajectory. The process of stopping the vehicle includes the speed reduction, which is obtained by lowering the drive moment and by applying the braking system. The movement equation for this type of a vehicle movement regime has the following shape:

$$m\frac{dv}{dt} = -F_r \tag{1}$$

Whereas F_r is the total resistance force which causes the vehicle braking. In this case, we assume the fact that during intensive braking, drive force of the vehicle is equal to zero. By adding a substitution: $dt = ds/v$ equation (1) gains the following shape:

$$m\,v\,dv = -F_r\,ds \tag{2}$$

By integral of equation (2) we gain an evaluation of speed change during the vehicle braking:

$$v = \sqrt{v_o^2 - \frac{2(s-s_o)}{m} F_r} \tag{3}$$

Whereas v is the current vehicle speed, s – distance passed by vehicle so far, m – vehicle mass, v_o i s_o speed and distance passed at the beginning of the braking process.
In case of intensive braking, the vehicle braking resistance force is equal to:

$$F_r = F_{bmax} = mg\varphi \tag{4}$$

Whereas $F_r = F_{bmax}$ is the maximum braking force the base can take, g – acceleration provided by gravity, φ the coefficient of adherence of the base.
Graph on *Figure 4* represents the changes of the speed given by equations (3) and (4), under different initial speeds at the beginning of the braking process, for a vehicle weighting one ton, and the coefficient of adherence $\varphi=0.8$.

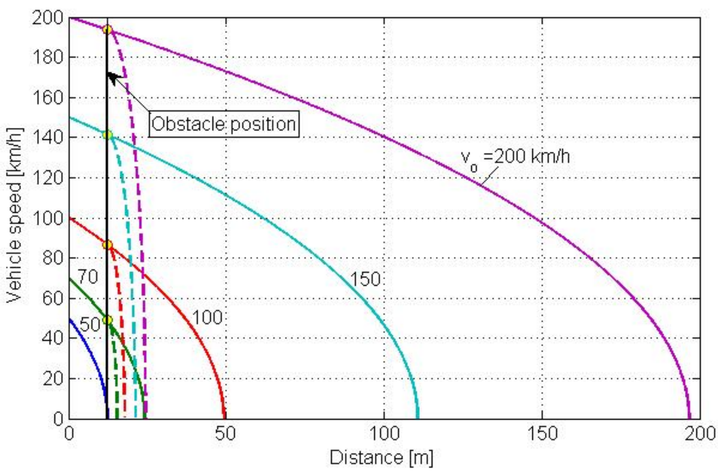

Figure 4 *Changes of speed during the braking process and obstacle impact at different speeds*

Safe stop is concluded only at initial speed $v_o=50$ *km/h*, considering that the obstacle is located at the position adequate to braking distance for this initial speed: $s_b=12.29$ *m*. At higher initial speed, braking distance is longer, so vehicle reaches the obstacle with different speed values which can be read from graph. The relation of Kinetic energy from the point when braking starts E_{ko}, and the one related to the obstacle E_{k2}, is shown by a graph on *Figure 5*. Graph also represents the change in kinetic energy which is absorbed by the braking system under the different initial speeds: $DE_k=E_{ko}-E_{k2}$. As it can be seen from the graph, that is a constant value which is adequate to the absorbed kinetic energy at the initial speed of *50 km/h*: $Ek_{50}=96.45$ *kJ*.

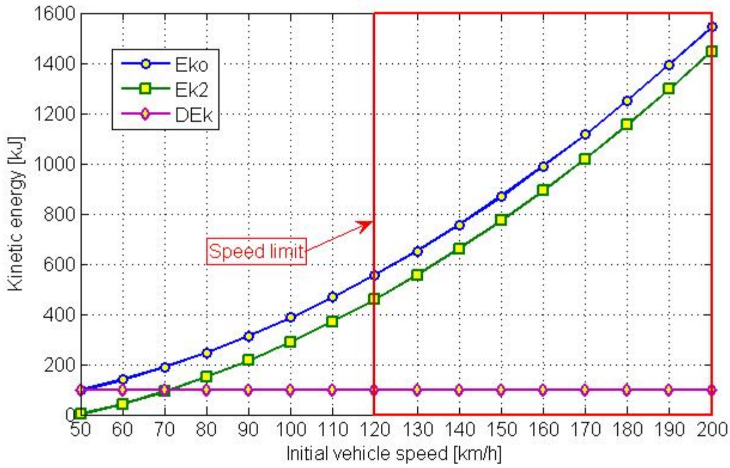

Figure 5 *Values of kinetic energy absorbed the braking system and kinetic energy on obstacle*

From the moment of obstacle contact, further change of vehicle speed depends on the character of the obstacle: mobile/immobile, crude/deformable. Resistance force which in this case stops the vehicle can be shown by a following formula:

$$F_r = - c_r x \tag{5}$$

Whereas c_r represents the resulting stiffness of the structures of vehicle and the obstacle, x- the amount of moving (deforming) after the contact.
Equation of the vehicle movement in this case is:

$$m\frac{dv}{dt} = -c_r x \tag{6}$$

That is:

$$m v \frac{dv}{dx} = -c_r x \tag{7}$$

Whose solution provides the change of vehicle speed after the contact with obstacle:

$$v = \sqrt{v_2^2 - \frac{c_r}{m}\left(x^2 - x_o^2\right)} \tag{8}$$

Whereas v_2 is vehicle speed at the moment of contact with the obstacle, x_o initial value of movement ($x_o=0$). According to equation (8), amount of speed reduction of the vehicle at the same value of initial movement speed V_2, depends on the stiffness of the system vehicle-obstacle (C_r), which is taken into consideration during the design of the frontal structure of the chassis. It is obvious that larger values of this crudeness lead to higher decelerations, and thus to potentially higher consequences of the traffic accident.

1.2 Effect of vehicle speed on cause and consequences of traffic accidents

The analysis to follow presents the effect of vehicle speed on dynamic processes during the case of traffic accident is conducted under the assumption that reactions of drivers and effects of other conditions (caraway and weather conditions) are the same. In real traffic conditions all of these factors are present, so their effect on traffic accident is very complex. The most objective evaluation of this effect can be gained by statistic analysis of results gained by expertise of the higher number of traffic accidents, which does represent the most common method of research. However, there is often a need to form models based on results of statistic analysis, whose usage allows more efficient research of this effect.
From all the models which can be found in literature, in this study we'll show Power Model of G.Nilsson [1].
This model is defined with a basic formula:

$$\frac{Fatal\ accidents\ after}{Fatal\ accidents\ before} = \left(\frac{Speed\ after}{Speed\ before} \right)^n \tag{9}$$

Whereas „before“ and „after“ are related to the values of speed vehicle has before and after the change from its mean value. The value of power of n, determined by statistic analysis of real data for different types of traffic accidents, are shown at *Table 1* [1].

Table 1 *Values of power of n [1]*

Accident or injury severity	exponent	interval
Fatalities	4.5	(4.1 – 4.9)
Seriously injured road user	3.0	(2.2 – 3.8)
Slightly injured road user	1.5	(1.0 – 2.0)
All injured road users (severity not stated)	2.7	(0.9 – 4.5)
Fatal accidents	3.6	(2.4 – 4.8)
Serious injury accidents	2.4	(1.1 – 3.7)
Slight injury accidents	1.2	(0.1 – 2.3)
All injury accidents (severity not stated)	2.0	(1.3 – 2.7)
Property-damage-only accidents	1.0	(0.2 – 1.8)

By using an equation (9) and values of power of n given in *Table 1*, we reached graphs shown on *Figure 6* for three basic categories of traffic accidents. From graph we can directly gauge the effect of change of average speed of the vehicle on the cause of studied types of traffic accidents.

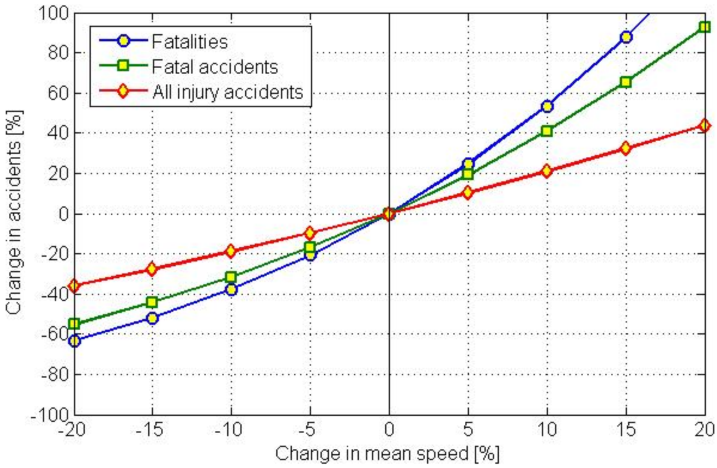

Figure 6 *The effect of vehicle speed on risk and severity of traffic accident*

In the same manner, we can gain the graphic dependency and gauge the effect of average speed for all other types of traffic accidents stated in *Table 1*.

2. TECHNOLOGICAL, ECONOMIC AND ECOLOGICAL ASPECTS OF INCREASING THE MAXIMUM SPEED OF CONTEMPORARY VEHICLES

Based on analysis done in previous chapters, we can come to following conclusions:

- the tendency to increase the maximum speed is present for all manufacturers,
- the average value of maximum speed of contemporary passenger vehicles reaches around 200km/h which is far higher then maximum speed allowed in most countries (120km/h),
- increase of average speed of the vehicles directly influences the risk and severity of the traffic accidents.

Bearing in mind the given conclusions, there is a need to analyze the need for such tendency under the criteria of requirements during the project phase of such vehicles as well as during exploitation and manufacturing.

2.1 Basic characteristics of the vehicles with higher maximum speed

Movement speed represents, definitely, the most exploitation parameter of the motor vehicles, with whose increase we directly shorten the travel time and goods transportation time, as long as its maximum value is corresponding to the limited regime which rarely occurs in public transportation. The value of maximum speed of the vehicles can be determined by the analytic method through basic movement equations [5]:

$$m\frac{dv}{dt} = \frac{M_e\, i_m\, i_o}{r_d}\eta - F_r \tag{10}$$

$$v_{max} = \frac{2\pi r_f \, n_{max}}{i_m \, i_o} \tag{11}$$

In this equations, following values are used: M_e – the effective engine momentum, i_m transmission ratio, i_o –transmission of main differential, η – degree of transmission usage, r_d – dynamic radius of the wheel, , r_f radius of radius of wheel tumbling, n_{max} -maximal engine revolutions.

Force of resistance F_r, , in equation (10), deals with forces: resistance of air F_v and tumble resistance F_f, , considering that the maximum speed of vehicle is determined on flat road, so the ascent resistance of the road is equal to zero. The vehicle movement regime which is adequate to maximum speed is gained from condition: $dv/dt=0$, that is:

$$M_e(n_{max}) = \frac{r_f \left(F_v + F_f\right)}{i_m \; i_o} \tag{12}$$

Where there is an assumption that there wont be pneumatic slip, ($r_d \approx r_f$), or losses in transmission ($\eta=1$). The equation (12) defines the value of the engine momentum which is supposed to provide the number of revolutions n_{max} under the effect of resistance force: F_v+ F_f, in the highest gear (for contemporary vehicles its $i_m=i_V$). The resistance to the movement of the vehicle is given by following formulas [5]:

$$F_v = \frac{1}{2} c_x \, \rho \, A \, v_{max}^2 \tag{13}$$

$$F_f = f \; G \tag{14}$$

Whereas c_x - aero dynamical coefficient of air resistance, ρ – air density, A – front vehicle surface, f – coefficient of tumbling resistance, G – vehicle weight. By replacing the form for movement resistances into an equation (12) it gains the following final shape:

$$M_e(n_{max}) = \frac{r_f \left(f\, G + 0.5 c_x \rho \, A \, v_{max}^2\right)}{i_V \; i_o} \tag{15}$$

The amount of power, which engine reaches in the regime of maximum speed, is provided by the known formula:

$$P_e(n_{max}) = M_e(n_{max}) \, \frac{\pi \, n_{max}}{30} \tag{16}$$

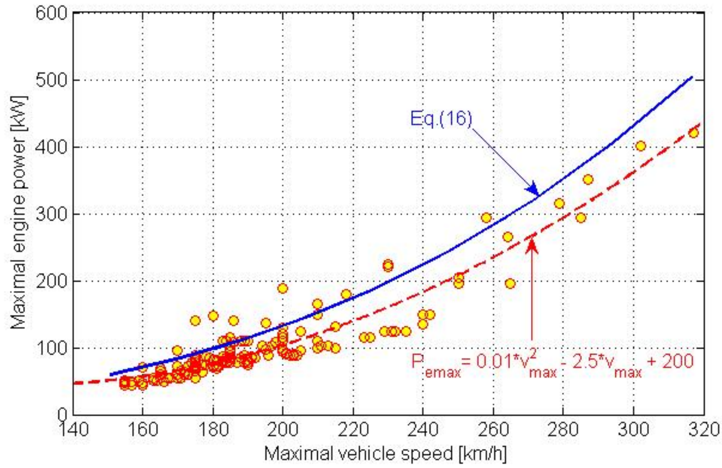

***Figure** 7 Dependency between the maximum engine power and maximum vehicle speed*

Graph on *Figure 7* shows the dependency between maximum engine power of maximum vehicle movement speed, provided by equations (15) and (16), and using the catalogue base of 170 contemporary vehicles which are approximated by the interpolating polynomial of 2nd degree. We can notice how the law of change of given curves goes together, which leads to a conclusion that by increasing the maximum vehicle speed, under all other remaining conditions being same, maximum power increases by the law of square parabola.

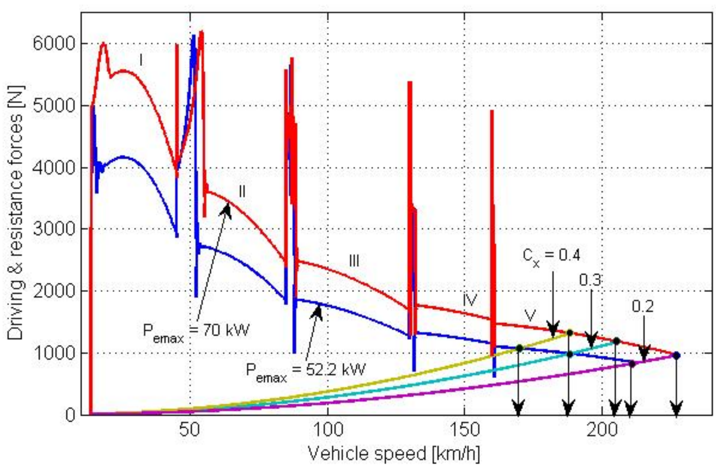

***Figure 8** Determining the work points in which the maximum movement speed of the vehicles is reached*

From equations (15) and (16) we can notice that all other parameters which have effect on the maximum vehicle speed. The direction of their effect is illustrated on *Figure 8*, which shows the dependency of forces of drive and of resistance of the vehicle on the movement speed in certain gears. As it can be seen from graph the increase of maximum speed of the vehicle can be reached by an optimal combination of increase in power of the engine and by lowering the movement resistance and the transmission ratio. The effect of maximum number of engine revolutions n_{max} on the value of maximum speed is provided by equation

(11). Irrelevant that the maximum number of engine revolutions does not coincide with number of revolutions during the maximum power (especially at otto engines) due to relatively small different we are taking them as coinciding by an agreement.

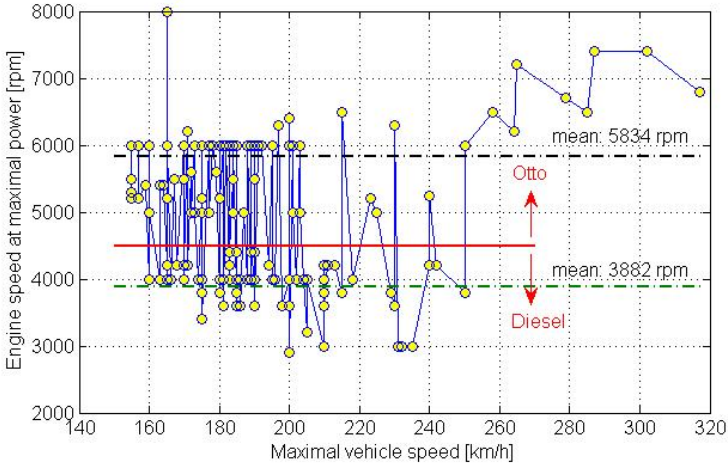

Figure 9 *Engine speed under which the maximum power is reached*

According to equation (11) under the same values: wheel radius and transmission ratio, by increasing the maximum number of revolutions per minute maximum speed is increased as well. However, from the graph on *Figure 9*, contemporary engines of passenger vehicles have fairly similar constants for number of revolutions under maximum power, to the value of 250km/h. The average values of those number of revolutions are: ≈6000 o/min, at otto engines and ≈4000 o/min for diesel engines. Thus, the vehicles with diesel engines under the same maximum speed need to have lesser values of transmission ratio and thus higher torque ratio under the number of revolutions n_{max} in relation to vehicles with otto engine. Vehicles which acquire maximum speed over 250km/h, are in the category of sport vehicles, at which their maximum speed increase is followed by the adequate increase in number of revolutions, as it can be seen on the graph on *Figure 9*.

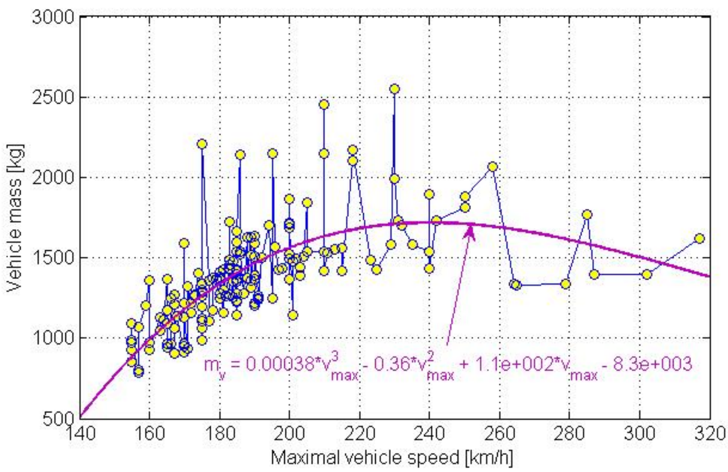

Figure 10 *Effect of the vehicle mass*

The effect of mass on vehicle movement can be gauged by an equation (10) from which follows that, under the same conditions, by reduction of vehicle mass leads to increase in vehicle speed. However, graph on Figure 10 shows a value increase tendency for serial vehicles up to the maximum speed of ≈ 240 km/h. This phenomena can be explained by the fact that maximum speed increase of serial vehicles is followed by category increase, and thus with vehicle dimensions. Only in category of sport vehicles v_{max}□*250 km/h*), the tendency to reduce the vehicle mass is present.
According to research available in the literature (3), the increase of maximum vehicle speed over some other values affects the consumption of fuel and emission of harmful components of the vehicle negatively, which also has to be taken into consideration in analysis such as this one.

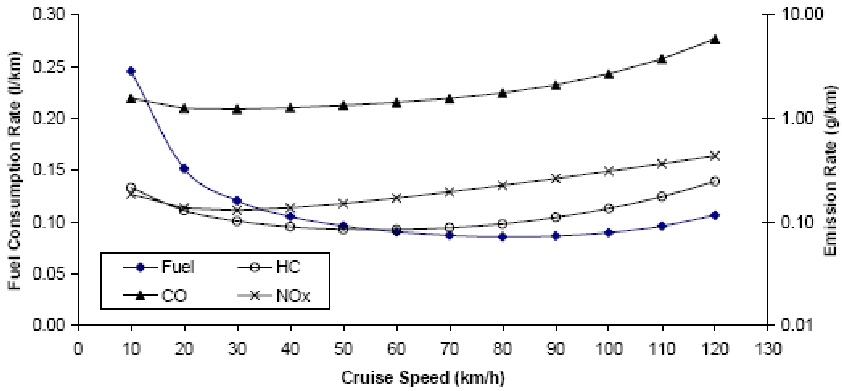

Figure 11 *Effect of movement speed on fuel consumption and emission of toxic materials [3]*

Graph on *Figure 11* shows exactly such dependencies, for which we need to mention that under the same movement speed value, the amounts of fuel consumption and toxic material emission depend on vehicle acceleration, so with the increase of acceleration value , those values increase as well.

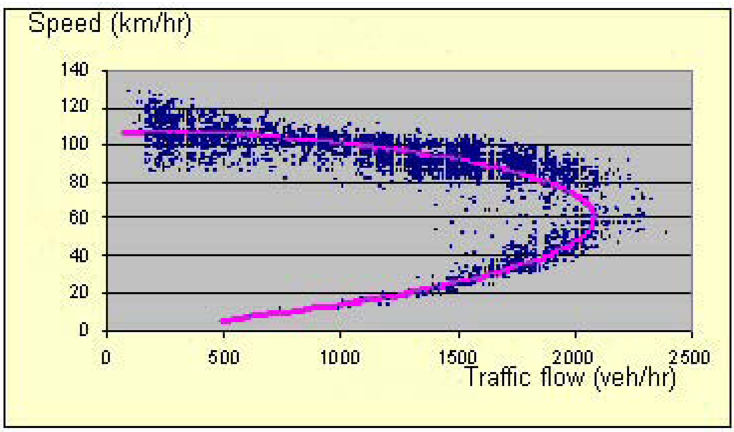

Figure 12 *The effect of average speed on vehicle flow (number of vehicles per hour) [2]*

Early stated fact that with an increase of average speed we reduce travel time and goods transportation time can not be generalized for all speed values. Graph on *Figure 12* shows exactly that for urban traffic line with 2x2 traffic tracks highest vehicle flow can be acquired for speeds averaging between 60 and 70km/h. Thus, with speeds above 70km/h, vehicle flow reduces and simultaneously traffic accident risk and severity of traffic accident consequences increase, which is exactly the reason to induce speed limits in the urban zones.

CONCLUSIONS

In the introduction part of the conclusions, we'll first quote two illustrative attitudes from document [2]:

- *"Speeding -- i.e. excessive and inappropriate speed -- is a widespread social problem as, typically, at any time 50 % of drivers are above the speed limits. It is the number one road safety problem in many countries, often contributing to as much as one third of fatal accidents and speed is an aggravating factor in the severity of all accidents".*
- *"Higher vehicle speeds also contribute to increased greenhouse gas emissions, fuel consumption and noise and to adverse impacts on quality of life, especially for people living in urban areas".*

Based on data analysis done in previous chapters we can add the following attitudes to quoted ones:

- tendency to increase maximum speed for contemporary vehicles has for a consequence an increase in production costs of vehicle and its components,
- in order to reduce the risk of traffic accidents it is necessary to include limits for values of maximum movement speed of vehicles and to apply complex measures of control of such regulations,
- rational solution to such problems is definitely to limit the maximum speed of serial vehicles based on the values which are closer to before stated limits,
- maximum speed of contemporary vehicles from the aspect of their manufacturers is practically a marketing move only, considering the fact that such speeds cannot be attained in the conditions of public transportation.

REFERENCES

[1] Elvik R., Christensen P., Amundsen A.: Speed and road accidents, An evaluation of the Power Model, TOI report 740/2004, Oslo 2004.
[2] Speed Management, Summary document, OECD, Europen Conference of Ministers of Transport, Januar 2004.
[3] Rakha H., Ding Y.: Impact of Stops on Vehicle Fuel Consumption and Emissions
[4] Garrard J.: Safe speed: promoting safe walking and cycling by reducing traffic speed, Safe Speed Interest Group, November 2008.
[5] Simić D.: Motorna vozila, II izdanje, "Naučna knjiga", Beograd 1977.
[6] Radonjić D., Janković A.: An influence of the internal combustion engine characteristics upon the traffic safety in the regimes of overtaking, Mobility & Vehicle Mechanics, Volume 36, Number 1, March 2010, p.7-26

[1]INFLUENCE OF DETERIORATION OF VIBRATION PARAMETERS ON MOTOR VEHICLE'S VIBRATION COMFORT

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UDC:629.3:531.1

Abstract

A model based dynamic simulation has a significant role during motor vehicle's development. A role of modeling is very significant in the preliminary phases of design - in definition of governing parameters. In practice, it is usually assumed that the vehicle's vibration parameters are constant during exploitation, which is basically incorrect. Namely, all the research shows that there is vibration parameters deterioration during exploitation and, thus, there are changes in motor vehicle's dynamic characteristics. In this paper, an attempt is made, based on preliminary results, to point to the fact that these changes should also be considered in preliminary phases of vehicle design.

Key words: vehicle, vibration parameters, deterioration, comfort

PRILOG ISTRAŽIVANJU UTICAJA DEGRADACIJE KARAKTERISTIKA OSCILATORNIH PARAMETARA NA OSCILATORNU UDOBNOST MOTORNIH VOZILA

UDC: 629.3:531.1

Rezime

Tokom razvoja motornih vozila, značajnu ulogu ima dinamička simulacija, koja je zasnovana na modeliranju. Uloga modeliranja je veoma značajna u prvim fazama projektovanja, tokom definisanja opredeljujućih parametara. U praksi se obično pretpostavlja da su oscilatorni parametri vozila tokom eksploatacije nepromenljivi, što u osnovi nije tačno. Naime, sva istraživanja pokazuju da tokom eksploatacije dolazi do degradacije oscilatornih parametara i, zbog toga, promene dinamičkih karakteristika motornih vozila. U ovom radu će biti učinjen pokušaj da se, na osnovu preliminarnih rezultata, ukaže na činjenicu da se i u ovim najranijim fazama projektovanja te promene uključe u razmatranje.

Ključne reči: vozilo, oscilatorni parametri, degradacija, oscilatorna udobnost

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INFLUENCE OF DETERIORATION OF VIBRATION PARAMETERS ON MOTOR VEHICLE'S VIBRATION COMFORT

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UDC: 629.3:531.1

1. INTRODUCTION

Dynamic simulation based on modeling of designed systems has an important role in motor vehicles development process. In practice, a whole range of vehicle models is used [4, 5, 7-13, 23]. Let's assume that a mechanical model of the observed motor vehicle is described, in general, by differential equation [5, 6]:

$$\dot{Z} = \dot{Z}\left(Z, A, U, L, Q, t\right) \tag{1}$$

where:

Z - is a vector of generalized coordinates of the vibration system,

A - is a vector of system vibration parameters,

U - is a vector of control functions,

L - is a function that considers random variations of vibration parameters characteristics during vehicle exploitation,

Q - is excitation time function (originating from road roughness, engine operation, unbalanced masses, tire nonuniformity) and

t - is time.

General solution of the differential equation (1) may be written in the following form [3]:

$$Z = Z(A, U, L, t) \tag{2}$$

A simple case is when there are no control functions (U=0) and changes in vibration parameters during exploitation are not considered (L=0):

$$Z = Z(A, t) \tag{3}$$

Simplification given by equation (3) is most frequently used in practice - the influence of the length of exploitation on change of vehicle's vibration parameters is neglected. However, it represents a major simplification, because data from [21] show that deterioration of the mentioned vibration parameters does exist.

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2. SELECTION OF A MODEL

Structure of a vehicle model is selected depending on the quantities that should be observed. In this case, an oscillatory model from [8] is used that is acceptable because it includes influences of all vibration parameters, as well as parameters of tire nonuniformity, during a vehicle straight line drive.

The observed model is presented in Figure 1 and it enables the analysis of:

- longitudinal, q(1), lateral, q(2), and vertical vibrations, q(3), as well as roll, q(4), pitch, q(5), and yaw, q(6), of the vehicle body,
- tire vertical vibrations, q(7), q(8), q(9) and q(10),
- propulsion group vertical vibrations, q(11),
- driver's seat vertical vibrations, q(12) and
- radial, r, tangential, t, and axial, n, vibrations of the steering wheel.

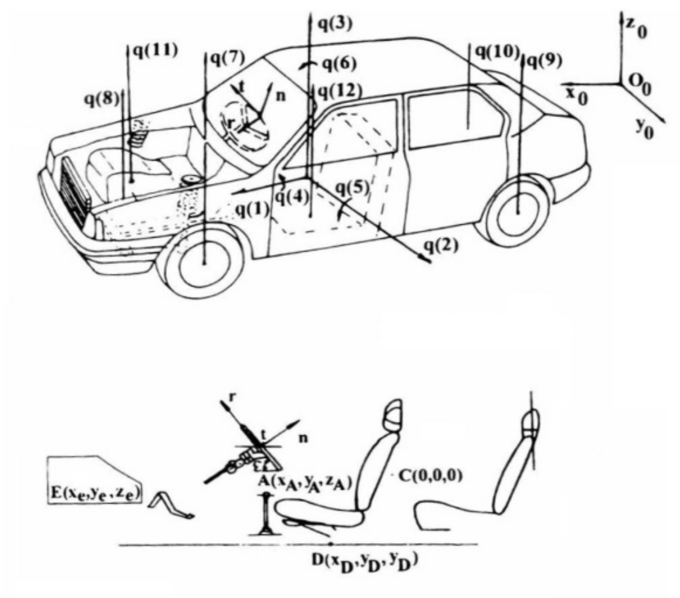

Figure 1: *Vehicle model [8]*

Here should be stated that differential equations of vehicle motion may be obtained in a classical way or by using software, and the motion is described by ordinary nonlinear differential equations like [18, 19, 21, 22, 24-26, 29, 30]:

$$M\ddot{q} + Kq = QE \tag{4}$$

where:

M - is a matrix of inertial parameters with dimensions NDFxNDF (NDF - number of degrees of freedom),

K - is a vector of Coriolis and centrifugal forces with dimensions 1xNDF,

QE - is a vector of generalized forces with dimensions 1xNDF,

$q, \ddot{q}$ - are matrices of generalized coordinates and accelerations, respectively, with dimensions NDFxNDF.

Matrices *M*, *K* and *QE* are calculated by classical procedure and are known form [8], so here they will not be presented here.

Vehicle vibrations originate from its motion over uneven roads with stochastic roughness, unbalanced operation of the engine and nonuniformities of the wheels and tires. Details may be found in [8-12].

Excitation forces originating from road roughness, engine operation and tires nonuniformity are introduced by vector *QE* (with dimensions 1xNDF) in which nonuniformity forces denoted with VVF_{11}, VVF_{12}, VVF_{21}, VVF_{22}, VLF_{11}, VLF_{12}, VLF_{21} and VLF_{22}, act beside known forces presented in Figure 2 (radial, tangential, lateral forces) and stabilization moments not presented in the Figure 2.

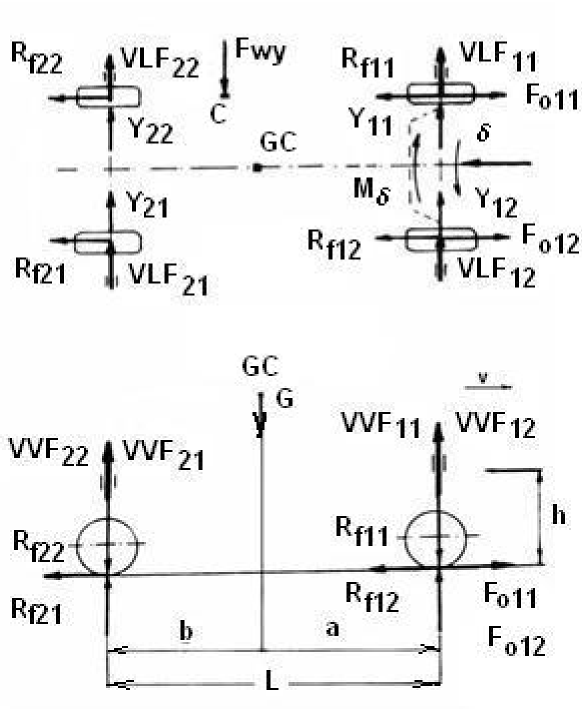

Figure 2: *Forces acting on the observed vehicle model*

As it is well known, vehicle dynamic parameters depend on the type of the road, vehicle speed and vehicle loads. Having this in mind, an analysis is conducted in the case of a vehicle with two passengers driving on a good asphalt road with speeds of 25 ms^{-1} and 40 ms^{-1}. The detailed description of definition of excitation functions from road roughness, engine operation and tires nonuniformity is given in [6-12], so it will not be presented here.

During analysis, the first three harmonics of tire nonuniformity were used [8]. Considering that there is statistical coupling between harmonics, the higher harmonics are expressed with the first harmonic of the radial (lateral) force.

The analysis is conducted for “ZASTAVA 1100” vehicle, with parameters obtained from the vehicle producer.

3. THE METHOD

The three groups of parameters were used for analysis of changes in vehicle dynamic characteristics in function of variations in vibration parameters during exploitation, with corresponding factors to take into account these variations. More precisely, any change is defined by the expression (5):

$$oscpar(\tau) = oscpar_0 \bullet k_i \tag{5}$$

where:

$oscpar(\tau)$ - is a value of any oscillatory parameter after τ kilometres of exploitation,

$oscpar_0$ - is a value of any oscillatory parameter at the beginning of exploitation and

k_i - is a factor that takes into account degradation of oscillatory parameters during exploitation.

Analyses have shown that stiffness and damping of elasto-damping elements decrease during exploitation [21], while it is assumed (based on experience) that parameters of non-uniformity increase with longer exploitation.

In order to take into account the influence of deterioration on vehicle dynamic characteristics in exploitation, corrective factors are adopted based on [21] and own experience [7] and presented in Table 1. Factor k_1 is related to springs, factor k_2 to dampers, factor k_3 to seats, drive unit mounts and tyres and factor k_4 to tyre non-uniformity. Three groups of factors were observed: at the beginning of exploitation (group 1), after 10.000 km of exploitation (group 2) and after 100.000 km of exploitation (group 3). All analyses were performed assuming that, in the observed period of exploitation, one complete change of tyres was performed, while other systems and elements were not replaced.

Table 1: *Corrective factors*

	k_1	k_2	k_3	k_4
Group 1	1	1	1	1
Group 2	0,95	0,83	0,50	0,50
Group 3	0,95	0,83	1	1

Differential equations that describe the oscillatory motions of the vehicle are solved numerically, using the Kutta-Merson method, with initial integration step of 0,01 s, for 256 points. During numerical integration, there were different integration step sizes, but the software written in Pascal [8] enabled the forming of sequences with integration step of 0,01 s, ensuring reliability of the results in the range between 0,4 Hz and 50 Hz that is quite acceptable for these types of analyses [1-3, 6-15, 17]. Since the results of the frequency analysis will be used only for mutual comparison, it was not necessary to calculate statistical errors, according to theory from [1-3].

4. DATA ANALYSIS

Based on acquired time series of passenger, seat and steering wheel accelerations, amplitude spectra are calculated using software [16] and shown in Figures 3 to 7.

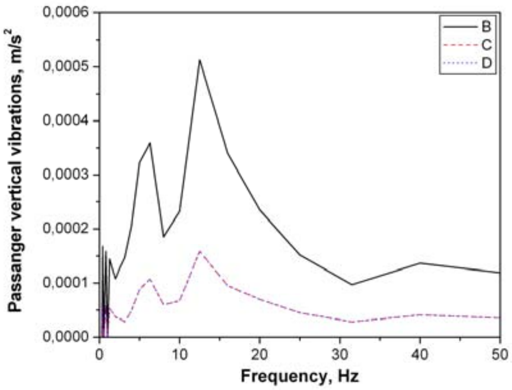

Figure 3 *Passenger vertical vibrations (B - group 1, C - group 2, D - group 3)*

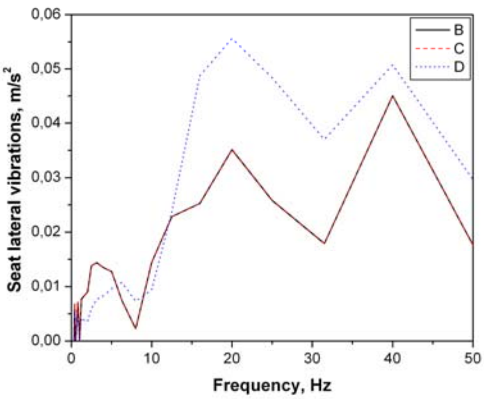

Figure 4 *Seat lateral vibrations (B - group 1, C - group 2, D - group 3)*

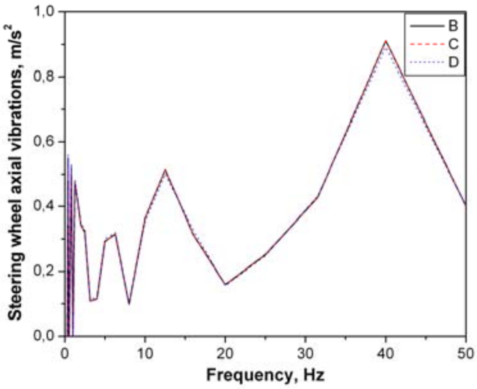

Figure 5 *Steering wheel axial vibrations (B - group 1, C - group 2, D - group 3)*

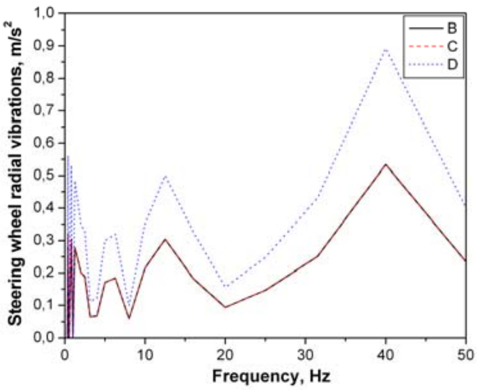

Figure 6 *Steering wheel radial vibrations (B - group 1, C - group 2, D - group 3)*

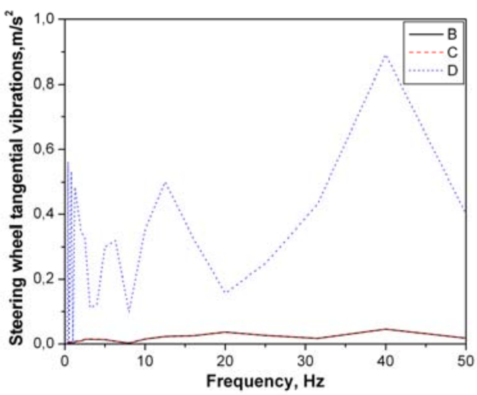

Figure 7 *Steering wheel tangential vibrations (B - group 1, C - group 2, D - group 3)*

Analysis of data in Figures 3 to 7 shows that the influence of oscillatory parameters deterioration on vehicle dynamic characteristics can be established. Detailed analysis determines that the influence is not unambiguous and that it depends on acceleration of the observed point and on the type of parameter deterioration. Besides, differences are very distinctive in frequency ranges where the humans are very sensitive to vibrations [13-17].

It may be established from Figure 3 that there are very small differences between passenger vertical vibrations for parameter groups C and D, but the differences are considerable for vibrations obtained for group B parameters.

Data in Figure 4 point to the fact that there are very small differences between seat lateral vibrations for parameter groups B and C, while there are considerable differences for group D parameters.

Regarding the steering wheel vibrations (radial, tangential and axial), Figures 5, 6 and 7, there are very small differences obtained for parameter groups B and C, but there are significant differences for vibrations obtained for group D parameters.

Previous discussions show that the influence of deterioration of vibration parameters is not unambiguous for all characteristic vehicle points, so there is a need to conduct separate analysis for each case. It should be noted that the influence of deterioration of vibration parameters must be considered during model development in the initial stages of vehicle design.

CONCLUSIONS

The following conclusion may be stated based on conducted research:

- Deterioration of vibration parameters during vehicle exploitation has considerable influence on changes of characteristics important for motor vehicle's vibration comfort.
- The influence of deterioration is not unambiguous in all characteristic points of the vehicle and there is a need to conduct separate analysis for each concrete case.
- The influence of deterioration of vehicle vibration parameters must be taken into account during model development in the initial phases of vehicle design.

ACKNOWLEDGEMENT

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REFERENCES

[1] Bendat, J, Pierson, A.: "Engineering applications of correlation and spectral analysis", John Wiley and Sons, New York, 1980

[2] Bendat, J. Pierson, A.: "Random data analysis and measurement", John Wiley and Sons, London, 2000

[3] Bendat, J.: "Nonlinear Systems - Techniques and Applications", John Wiley and Sons, London, 1998

[4] Dushin, S.E. et all.: "Modeling of systems and complexes" (in Russian), ITMO, Saint Petersburg, 2010

[5] Demić, M.: "Scientific methods and technological development" (in Serbian), Faculty of Mechanical Engineering, Kragujevac, 2011

[6] Demić, M.: "Optimization of motor vehicles vibration systems" (in Serbian), Faculty of Mechanical Engineering, Kragujevac, 1997

[7] Demić, M.: "Passenger cars design" (in Serbian), Faculty of Mechanical Engineering, Kragujevac, 2004
[8] Demić, M. et all.: "A Supplement to Standardization of Nonuniformity of Passenger Car Tires With Respect to Oscillatory Comfort and Handling", ISATA, Milan, 1984
[9] Demić, M.: "The definition of the tires limit of admissible nonuniformity by using the vehicle vibratory model", Vehicle System Dynamics Vol. 31 (3), 1999, pp. 183-211
[10] Demić, M.: "Optimization of Vehicles Elasto-Damping Element Characteristics from the Aspect of Ride Comfort", Vehicle System Dynamics, Vol. 23, 1994, pp. 351-377
[11] Demić, M.: "Optimization of Characteristics of Elasto-Damping Elements from the Aspect of Oscillatory Comfort and Vehicle Handling", International Journal of Vehicle Design, Vol. 17, No. 1, 1996
[12] Demić, M., Diligenski, Đ., Demić, I., Demić, M.: "A method of vehicle active suspension design", Forsch. Ingenieurwes., Vol. 5, No. 70, 2006, pp. 145-158
[13] Demić, M., Lukić, J.: "Human Body Under Two-Directional Random Vibration", Journal of Low Frequency Noise, Vibration and Active Control, Vol. 3, 2008, pp. 185-201
[14] Demić, M., Lukić, J.: "Investigation of the transmission of fore and aft vibration trough the human body", Applied Ergonomics, Vol. XXX, 2009, pp. 1-8
[15] Demić, M., Lukić, J., Milić, Ž.: "Some aspects of the investigation of random vibration influence on ride comfort", Journal of Sound and Vibration, Vol. 1, 2002, pp. 109–129
[16] Demić, M.: "Analsigdem - Software for signal analysis", www.ptt.yu/korisnici/i/m/imizm034/index.swf, 2003
[17] Griffin, M. J.: "Handbook of Human Vibration", Academic Press, London, 1990
[18] Featherstone, R.: "Rigid Body Dynamics", Springer, 2008
[19] Genta A.: "Motor Vehicle Dynamics", Politecnika di Torino, 2003
[20] Gillespie T.: "Fundamentals of Vehicle Dynamics", SAE, Warrendale, 1992
[21] Magneti Marelli: Informations, 2012
[22] Miliken W.F., Miliken D.L.: "Race Car Vehicle Dynamics", SAE, Warrendale, 1995
[23] Miloradović, D.: "Research of mechanical and functional couplings of vehicle's dynamic system from the aspect of required performances" (in Serbian), Ph.D. Theses, Faculty of Engineering, Kragujevac, 2012
[24] Rajamani, R.: "Vehicle Dynamics and Control", University of Minesota, 2005
[25] Rašković, D.: "Analytical mechanics - short course" (in Serbian), Faculty of Mechanical Engineering, Kragujevac, 1974
[26] Simić, S.: "Analytical Mechanics: Dynamics, Stability, Bifurcation" (in Serbian), FTN publishing, Novi Sad, 2006
[27] Tarasik, V.P.: "Mathematical modeling of technical systems" (in Serbian), DesignPro, 2004
[28] Schwab, A. L.: "Multibody Dynamics B, Lecture notes", TU Delft, wb1414, course 1997/1998
[29] Schiehlen, W.: "Anleitung Programmsystem NEWEUL" (in German), Institute fur Mechanik B, 2000
[30] Fabien, B.: "Analitical System Dynamics – Modeling and simulation", Springer, 2009
[31] Zastava: Informations, 1977-2010

[1]DESIGN OF THE MOTOR VEHICLES FROM THE ASPECT OF HIGH STRENGTH STEELS APPLICATIONS

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Danica Josifović, PhD full professor, ***Vukić Lazić***, PhD full professor

UDC: 621.112

Summary

Design of the motor vehicles from the aspect of high strength steels applications is considered in this paper. Specific problems of applications in motor vehicles are put in correlations to characteristics and properties of this steel grade. The nature, characteristics and properties of high strength steels are briefly discussed in the paper to establish the set of influential factors related to design of motor vehicles from the aspect of high strength steels applications. High-strength low-alloy steels are the materials with currently fastest growing share of application in motor vehicles. Those steels have significantly different characteristics from the characteristics of conventional steels that they replaced. The market demands that are put on design of motor vehicles even enlarge the usage of high strength steels in motor vehicles. The advantages of usage of this steel grade are put in correlations with particular mechanical design procedures which are required by those applications. The concrete tasks in design procedures of motor vehicles which are related to applications of those steels are recognized in this paper. It is concluded in the paper that applications of high strength steels in motor vehicles put new significant perspectives in design, but, also, brings some problems that must be solved in process of design of motor vehicles. The applications of high strength steels in the elements of motor vehicles provide many positive effects on affordability, safety, reliability and duration of exploitation period. The full advantages of applications of high strength steels in motor vehicles can be realized only by optimization of its design procedures due to specific characteristics and properties of high strength steels.

Key words: Design, motor vehicles, high strength steels

DIZAJN MOTORNIH VOZILA SA ASPEKTA PRIMENE ČELIKA POVIŠENE JAČINE

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Rezime

U radu je razmatran dizajan motornih vozila sa aspekta primene čelika povišene jačine. Specifični problemi vezani za ovu primenu stavljeni su u korelaciju sa karakteristikama i osobinama ove vrste čelika. Priroda, karakteristike i osobine čelika povišene jačine su ukratko razmatra111ne u radu da bi se ustanovio skup uticajnih faktora koji se odnose na dizajn motornih vozila sa aspekta primene čelika povišene jačine. Nisko legirani čelici

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povišene jačine trenutno predstavljaju materijal sa najbržim rastom udela primene u motornim vozilima. Ovi čelici poseduju značajno različite karakteristike u odnosu na konvencionalne čelike koje zamenjuju. Tržišni zahtevi koji se postvljaju pri dizajnu motornih vozila čak uslovljavaju širenje upotrebe čelika povišene jačine. Prednosti primene ovih čelika su stavljene u korelaciju sa konkretnim postupcima tokom dizajniranja koje zahteva ova primena. Konkretni zadaci u postupku dizajna koji se odnose na primenu ove vrste čelika su prepoznati u ovom radu. U radu je zaključeno da primena čelika povišene jačine otvara nove, zanačajne prespektive u dizajnu, ali takođe i donosi konkretne probleme koji se moraju rešavati tokom dizajniranja motornih vozila. Primenom čelika povišene jačine kod elemenata motornih vozila ostvaruju se mnogi pozitivni efekti u smislu dostupnosti, sigurnosti, pouzdanosti i trajanja perioda eksploatacije. Puna prednost primene čelika povišene jačine kod motornih vozila može se ostvariti jedino optimizacijom njihovog dizajna u odnosu na specifične karakteristike i osobine čelika povišene jačine.

Ključne reči: dizajn, motorna vozila, čelici povišene jačine

DESIGN OF THE MOTOR VEHICLES FROM THE ASPECT OF HIGH STRENGTH STEELS APPLICATIONS

Andreja Ilić[1], PhD student, ***Lozica Ivanović***, PhD associated professor,
Danica Josifović, PhD full professor, ***Vukić Lazić***, PhD full professor

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INTRODUCTION

The present motor vehicle industry is focused on developing vehicles with higher safety, reduced fuel consumption, improved reliability by production processes that are more cost efficient. Those demands are opposite by nature with very complex interactions. The partial solution of problems can be accomplished through optimization of design and the continuous usage of newer, lighter and stronger materials. The controls of raw and prefabricated materials, so as their processing technology, come to the focus of testing methodologies. The listed tendencies at the area of motor vehicle industry cause the improvement of existing technologies, so as the development and differentiation of new, advanced methods of elements' joints realizations. In addition, the analyses of demands which are founded in vehicle design, at automotive industry especially, show that modern vehicles have, beside the primary function, numerous and very different additional functions. From the other side, they have to fulfill very strict requirements, which are fundamentally different. The estimated requirements and criterions often have complex system of interactions. All the presented facts must be adequately considered in the process of the vehicles design.

The present materials that are used for modern vehicles are very diverse by nature. From the aspect of design, material selection is one of the most important procedure at the process of the product development.

The bodies of first cars were built mostly of wood while engines were made of iron. Later, with evolution of vehicles, the steel body panels were used on wood frames with steel body panels. At the early years of 20th century the principle of body on frame was used at the current design of the vehicles. Those vehicles had chassis that supported all the parts and the body that was made of steel. Current design uses monocoque body solution especially for passenger cars and small sport utility vehicles. Heavy vehicles like trucks and busses uses the bodies on frames design solutions.

The steel is dominant material for making present vehicles due to specific characteristics and properties. With evolution of steel grades to high strength low alloyed steels and application for vehicles this steel grade become most important material. High-strength steels are the materials that fulfill the requirements for mass reduction, improve energy efficiency, reduced fuel consumption in present vehicle industry without compromising in safety and affordability. The lightweight capability of high-strength steels resulted from theirs microstructure, obtained through highly controlled production processes and combinations of micro alloying elements. Very beneficial combination of strength and ductility of high-strength steels implicate that this steel grade must be considered differently from the other steel grades during design process. This fact is the basis hypothesis for this

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paper. The research shown in the paper is done by relevant literature overview related to this area. The results presented in the relevant literature were analyzed and put into relationship with modern demands in vehicle design. The aim of this paper is to identify the design aspects at vehicles with high-strength steels application. Also, the perspectives of this application are highlight in this paper. The conclusion of investigation presented in the paper is that high-strength steels provide lightweight and environment friendly capability in vehicle design with sustainable prices, remained reliability and even improved safety [16, 2, 3 and 4].

THE BASIC CHARACTERISTICS OF HIGH STRENGTH STEEL GRADES

The high strength steels are developed in order to provide the favorable mechanical properties and higher corrosion resistance in relation to conventional carbon steel grades. Those steel grades are not classified as alloyed steel grades in common manner because its main requirements are defined mechanical properties. The chemical compositions of those steel grades are of less importance. The chemical compositions of those steel grades can even vary in order to ensure the homogeneity of mechanical characteristics by those variations. The high strength steels are usually produced as sheets and plates with low carbon content (0.05% to 2%), while manganese content is not higher than 2.0%. The sheets and plates are characterized by an extremely uniform surface and homogeneous microstructure across the entire cross-section. Those steels also contain small amounts of nickel, molybdenum, copper, nitrogen, vanadium, niobium, titan, zirconium and boron. By this combination of allying elements and their quantities, the proper weldability and deformability are obtained. Also, high strength steels are suited to different cutting techniques. This is achieved through highly controlled production processes special alloy design and a high degree of purity with respect to non-metallic inclusions. The production technologies are designed to minimize residual stresses and to avoid deformations [17 and 14].

The technological production process conditioned its microstructure and by that also conditioned its properties. The nature of microstructure of high strength steels, so as theirs characteristics must be considered adequately in design process. The microstructure of low alloyed high strength steel is typically fine grained after the production processes and consisted of fine ferrite (α) grains with uniformity of shapes. In addition, the small amounts of cementite is present in microstructures of those steels, so as fine dispersed particles of carbon nitride (Fig.1.) [17].

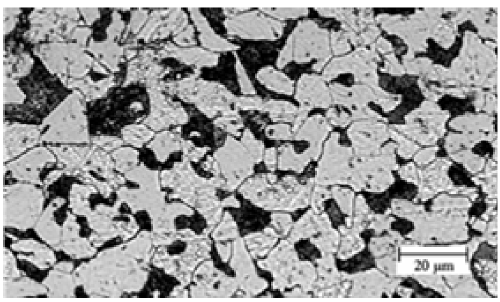

Fig.1: *Typical microstructure of high strength steels [17]*

During the final rolling process, the favorable conditions for creation of the large numbers of referent locations within the distinct formation of α metal grains. The locations, where energy level for formation of α metal grains, are dislocations, the grain binderies and sub-grains, duplicated grains, the deformation lines. The density of those locations in micro structure of those steels is the consequence of production process and level of its deformation during the production. As consequence of production process at high temperatures, the effects of microstructure regeneration are present, such as recuperation and recrystallization.

During production process of steels, the different phenomena, with opposite consecutive processes, are induced. Those phenomena cause increase, so as decrease of dislocation density. The recrystallization process is suppressed by decrease of speed of grains' nucleuses formation and by the reduction of movement of metal grains and sub grains boundaries. The recrystallization process is consequence of the presence of alloying elements' atoms in solid soluble of steels and it is induced by continual rolling with short break periods, when the effects of niobium are dominant. In addition, recrystallization process is induced as the consequence of precipitation during reversible rolling with longer break periods, when the dominant process is separation of carbon nitride. The development of high strength steels are linked to the technology of thermo-mechanical controlled process that provides highly controlled microstructure. The chemical composition of those steels conditioned its characteristics during production processes and final microstructure. Real microstructure and correspond mechanical properties are the result of very complex interaction of different and heterogeneous factors. The characteristics of high strength steels in exploitation are, on the other hand, the result of its microstructure and additional factors. The number and complexity of factors that influent to characteristic of material in exploitation conditioned that those characteristic can be determined only by experimental testing in real exploitative conditions [13 and 14]. The aim of stress-state analysis is formation of mathematical model to be verified by experimental testing. The numerical simulation of construction made of high strength steel answer to the exploitation conditions are one of the tool for identification of favorable design solution. Verification of design solution for construction made of high strength steels is done by experimental testing.

APPLICATION CHARACTERISTIC OF HIGH-STRENGTH STEELS IN VEHICLE DESIGN

The application of high strength steels in mechanical constructions can be considered from number of different aspects. In this paper, only the most significant aspect of this application is presented. The high-strength low-alloy steels with bainite or ferrite–pearlite microstructure are used for production of car bodies, shafts, elements of engines and so on. The high-strength steels with yield limit of 600 MPa are used for specific zones of car bodies [6]. For the analysis of application characteristics of high-strength steels in automotive industry, the example of car body presented at Fig. 2. is considered. Specific elements of car body are made of high-strength and high-strength low-alloyed steels in order to archive required strength and rigidity of car body with simultaneous reduction in its mass. By the aims of material selection and forming of those specific zones (Fig.2.), the beneficial mechanical properties are provided. Those zones represent the zones of energy absorption in case of collision and they improve passive safety of vehicles. Mechanical properties of selected materials provide decrease of dimensions of those specific zones and by that, increase of flexibility in car body design. The application of high strength steels for doors, cover of engine and trunk compartment provide 25% - 30% mass reduction to conventional steel applications with no additional cost [6, 11 and 12].

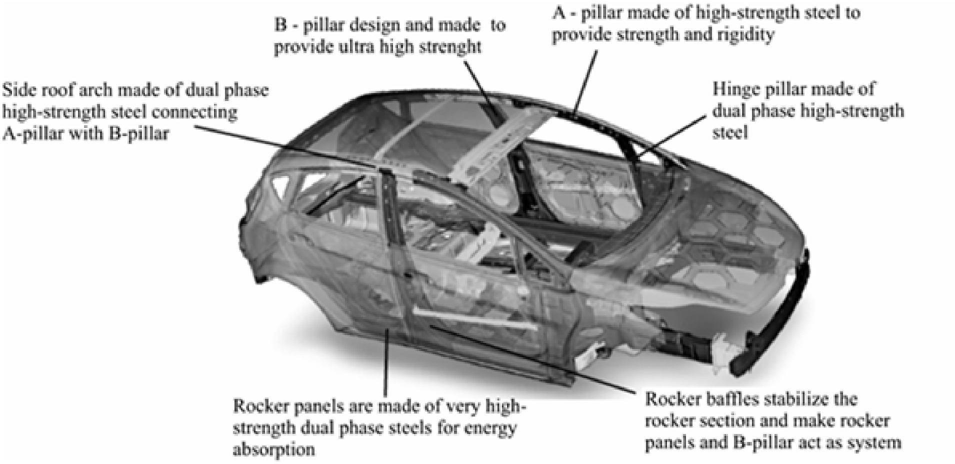

***Fig. 2**: Materials of specific zones of car body*

The adequate material selection, especially use of high strength steel provides very significant benefits. The passenger zones of the car body, according to passive safety requirements and regulations have to resist to deformations to prevent imposition in case of collision. The materials for this zone of the car body have to obtain sufficient strengths, so martensite, and boron steels are preferred (Fig. 3.). From the other side, intensive use of high strength steels provide additional positive effects such as mass reduction, flexibility of design, wide range and cost effective joining methods, and so on. Also, production processes of high strength steel grades provide very narrow tolerances of dimension and shape that is important for present press - lines and robotic joining methods in present automotive industry. The processing of high strength steel grade is comparable to processing of conventional steels, so additional costs for processing are minor. This fact is opposite to other materials that provide mass reduction without compromises in safety.

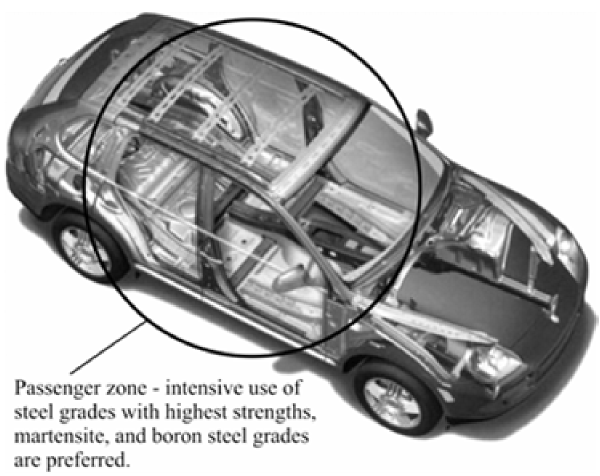

***Fig. 3:** Steel grades at passenger zone of car body made to resists deformation and provide passive safety*

The engine zone and trunk are zones that are intended to manage and absorb energy in case of collision. The design solution and material selection have to provide high energy absorbing, strength and ductility (Fig. 4.). The favorable materials for made of those zones are dual phase and transformation induced plasticity high strength steel (TRIP).

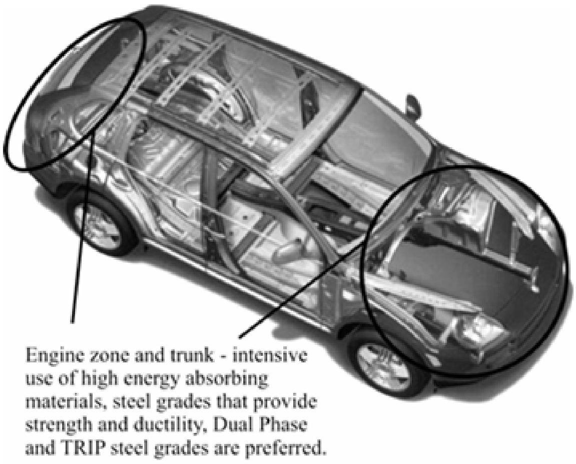

Fig. 4: *Steel grades for energy management zones of car body made to deform for absorb energy in collision*

The presented facts implicate that by the applications of high strength steels the higher level of flexibility in design is obtained [11 and 12]. Furthermore, the mass reduction makes ability for reduction of fuel consumption and further reduction of pollutant gases emissions. All this, reduced the complete ecological impact of production and exploitation of vehicles. Aggressive reduction of vehicles' mass by the application of high-strength steels and its design optimizations highlights the new tendencies in car design. In modern automotive industry, high concerns are put on passive safety. Behaviors of vehicle structure at collisions are analyzed, firstly, by numerical simulations and then experimentally tested. The major influential factors for behavior of vehicle structure in collision are the characteristic and mechanical properties of specific zones made of high-strength low-alloy steels.

JOINING METHODOLOGIES

In the area of present design of motor vehicles, one of the most critical factors in safety and reliability analysis are the joint zones of elements. Design of element joints zones represents the most complex procedure in the process of the motor vehicles development. The zones of elements joints are the zones with high level of stress concentrations and with high heterogeneity level of characteristics at the whole vehicle' structure. In present motor vehicles industry, different joining methodologies are used. Welding joints provide material continuity at the joint zones. Stress concentrations at vehicles' structures, as complex phenomena, can be analysed from large number of very different aspects. For example, it can be considered locally and structurally, in relation to dimension level of analysis. Different from other joining methods that required holes in the joining zone, the flow of stress lines at welded joints are beneficial. It is obvious that, from the aspect of stress concentration, this joining method is preferable in relation to other joining methods, which induced higher variations of stress lines. Also, from the aspect of high strength steels use in motor vehicles, the problems of welding of this steel grade are very important. Availability of welding technology, altogether with other aspects of this technology application, conditioned that this technology become dominant joining method in production of motor vehicles in cause were rejoin is not necessary. As consequence of applied technology of welding in the zones of the welds and in the heat affected zones the residual stresses are induced. Adequate welding technology represents the condition for providing required mechanical characteristics of welded joints zones and by that, the condition for proper joining. The literature related to the welding of high-strength low-alloyed steels showed that existing references are not satisfactory clear and precise. Using of those steels, for forming the elements in motor vehicles, is valid only if adequate joining methodology is provided. Intensive development of new steel grades must be followed with progress in welding procedures. Relatively high level of embrittlement that is the result of improved mechanical characteristics make this steel grade very sensitive to heat effects of welding in relation to conventional carbon and carbon-manganese steels. In relation to heat cycle of welding, the different transformations in microstructures are induced and those transformations lead to decrease in hardness and embrittlement in heat affected zone [5, 15 and 18].

Characteristic of formed zones at joints of the elements, made of high-strength steels, in motor vehicles can be degraded, generally, in three manners. Firstly, it is in case of using high energy of welding or when temperature of preheating is higher then allowed. Secondly, it is in case when energy level of welding or temperature of preheating is low and under the allowed limits. Thirdly, it is when the heat cycle of welding is related to heat cycle that induces segregation of some elements at the binderies of metal grains and forced degradation of toughness [1, 15 and 18]. With the improvement in mechanical characteristics, the diapason of allowed welding parameters is reduced and, by that, the risks of using welding parameters that are out of limits are higher. This fact must be considered properly, especially in case of high-strength low-alloy steel application in motor vehicles especially from the aspect of automated welding processes. The design solution of the elements of the motor vehicles must considered automated joining methodologies adequately.

DESIGN RULES FOR APPLICATION OF HIGH STRENGHT STEELS

The applications of high strength steels in mechanical constructions, so as in motor vehicles are regulated by Serbian national standard that is in agreement with Europe Union Norm -EUROCODE 3. This norm considered the application of high strength steels to steel grade S460. The Part 1-12 was added to EUROCODE 3 in order to enclose the application of high strength up to grade S700. The basic design rules and procedures regulated by EUROCODE 3 can be adopted to use at design of elements of motor vehicles made of high strength steels. But, there are not enough experimental data and information about characteristic and properties of joining zones of elements made of those steels at motor vehicles. The design rules for elements made of high strength low alloyed steels are still very limited and on the recommendation level. EN 1993-1-12 regulate the application of steels with characteristics and properties defined by EN 10025-6 and EN 10149-2. Those norms enclosed steels up to grade S960, but those steels with very high strenght do not have significant application in general purpose motor vehicles. EN 10149-2 defined the thermo-mechanically produced steels with favorable ability for additional processing and enclosed steel grades from S500 to S700, while theirs application is regulated by EN 1993-1-12. The obligation for impact toughness testing in norm EN 10149 is not proposed. Because of that, impact toughness testing of steels is regulated in EN 1993-1-12 by definition of minimal impact toughness as energy of 40 J at -20°C for fracture of sample [5].

The providing of adequate resistance to brittle fracture is regulated by norm EN 1993-1-1. The resistance to brittle fracture is obtained by selecting of materials with proper toughness and this norm does not provide any other recommendations for avoiding the brittle fracture [5]. The reason for this is economic because the other design rules based on the resistance to brittle fracture induced additional costs. The method for determining the minimal dimensions at cross section of element is given in norm EN 1993-1-10 and can be used also for elements made of high strength steels up to grade S690. Ductility of steel is its important mechanical properties that are not defined precisely. Norm EN 1993-1-1 proposes the general requrements for mechanical properties, but does not enclosed requirements for its ductility. From the aspect of ductility as design criterion, the special design procedure and rules must be used. The functional requirements for elements made of high strength low alloyed steels at motor vehicles are based on maintaining of strength in cases of high plastic deformations due to collision. The requirements for ductility of material are given at part 3.2.2(1) EN 1993-1-1 with recommended values. That recommended values are modified in part EN 1993-1-12 for application of high strength steels and they are presented as

$$\frac{f_u}{f_y} = 1,05, \tag{1}$$

where f_u - ultimate tensile strength and f_y - nominal values of yield strength and elongation at failure is less then 10%. Also, it is

$$\varepsilon_u \geq 15\frac{f_u}{E}, \tag{2}$$

where ε_u - the elongation at failure and E – elastic modulus. The analysis of stress-strain state in elements made of high strength steels is based on elastic analysis method and on nonlinear finite element method [5].

Buckling of elements made of high strength steels at structure of motor vehicles are rear, but significant and potentially dangerous problem. But, on the bases of reduced levels of material inhomogeneity, the elements made of high strength steels are more resistant to buckling than the same constructions made of different kind of steels. The criterions of design used for lower strength steels can be used even for high strength steels. Those criterions of design can be improved by the use of adopting additional factors to consider the higher resistance of material to buckling in relation to its homogeneity level.

Low alloyed high strength steels have good welding ability. But, welding of high strength steels reduced the diapason of available parameters for welding. In relation to that, the risk that welding parameters step out of defined limits is higher. Welding of high strength steels with filler materials of lower strength provide much ductile welds. Those welds are less sensitive to cracks. The using of those filler materials is not regulated by EN 1993-1-8, but it is regulated in part EN 1993-1-12. The design of those welded joins is based on strength of filler materials and not on the strength of parent material. For example, for T joints at materials with different strengths, the correlation factor have the value of $\beta_W = 0$.

On the bases of experimental testing of welded joints with filler materials with different strength to strength of parent material, the modification of relation in EN 1993-1-8 for design rule is done to the following form

$$\sqrt{\sigma_{\perp}^2 + 2\tau_{\perp}^2 + 3\tau_{\|}^2} \le \frac{f_u + f_{eu}}{2\gamma_{M2}}, \tag{3}$$

where is: $\sigma_{\perp}$ - is the normal stress perpendicular to the throat, $\tau_{\perp}$ - is the shear stress (in the plane of the throat) perpendicular to the axis of the weld, $\tau_{\|}$ - is the shear stress (in the plane of the throat) parallel to the axis of the weld [5]. In equitation (3) f_u is the nominal ultimate tensile strength of the weaker part joined, f_{eu} - the nominal tensile strength of material of filler material and γ_{M2} is partial safety factor for joint. The design criterion presented by equitation (3) can be used for welded joints with lower and higher filler materials strength to strength of parent material. On the bases of this design criterion the more uniform factor of safety are obtained in case of load that act at direction parallel to axis of the weld or in plain perpendicular to this axis.

The chemical composition of materials, characterized by carbon equivalents is dominant influential factor to the determination of preheating levels for the prevention of hydrogen cracking. Carbon equivalent (CE) formulae according to International Institute of Welding, and implemented in EN 1011-2:2001

$$CE = C + \frac{Mn}{6} + \frac{(Mo + Cr + V)}{5} + \frac{(Ni + Cu)}{15}[\%], \tag{4}$$

where the chemical symbols of elements present its concentration in percentage. The influence of the chemical composition on the cold cracking behavior of steels are expressed also as theoretic carbon equivalent (CET) and provides information on the effect on the individual alloying elements on these properties in relation to that of the carbon by following relation

$$CET = C + \frac{(Mn + Mo)}{10} + \frac{(Cr + Cu)}{20} + \frac{Ni}{40}[\%], \tag{5}$$

where, also, the chemical symbols of elements present its concentration in percentage.

As consequence of welding procedure a different types of defects are always present in zones of welds. The potentially most dangerous defects in welding of high strength steels are hydrogen cracks that are transversally oriented. Because of the difficulties in identification and determination of defect dimensions, the method of allowable level of defect is adopted. By this method, certain level of density of defects with defined properties is always present in the zone of welds. The value of allowable dimensions of defects depend to the impact toughness of material and in case of weld metal, also, depend on level of deformation in exploitation of motor vehicle structure.

CONCLUSIONS

High-strength low-alloy steels are the materials with currently fastest growing share of application in motor vehicles. Those steels have significantly different characteristics from the characteristics of conventional steels that they replaced. Their lightweight capability is linked to specific ratio of strength and toughness to weight, as result of complex, multi- phase microstructure. Mechanical properties, resistance to atmospheric corrosion, the availability of joining methods, beneficial economic and ecologic effects conditioned that this steel grade become very important from the aspect of application in motor vehicles. Also, from the aspect of evaluation of new type of steel from this steel grade, the further enlargement of application can be expected. The considerations of this paper are linked to application of first generation of high strength steels. The microstructure of the second generation of high strength low-alloy steels is, basically, austenitic at room temperatures due to high content of manganese. The step forward is done in forming technology of those steels by development of specific technology that induced the twinning of metal grains (TWIP - twinning induced plasticity). The deformation process of those steels induced the twinning of metal grains and by that, refinement of microstructure is obtained and resulted in high deformation reinforcement. The tension strength of those steels is higher than 1000 MPa with simultaneous deformation of 60%. The prices of those steels are very high due to high prices of alloying elements. The complex microstructure of those steels causes decrease of weldability. The mechanical properties of second generation of high strength low-alloy steels overcome the requirements of general purpose mechanical constructions. The evolution of high strength low-alloy steels is continued by development of the third generation of high strength low-alloy steels. The intended microstructure of the third generation of high strength low-alloy steels have to be less complex then the microstructure of the second generation, which will improve the weldability with minimal compromises in mechanical characteristics. Those intended properties of the third generation of high strength low-alloy steels will even induced expansion of their application in mechanical constructions [7, 8, 9 and 10].

By the application of high strength steels in motor vehicles a number of significant advantages in design can be done. The optimization of design of elements made of this steel grade in motor vehicles can be done only by adequate consideration of its specific nature and characteristic. Higher safety and load capacity, low weight, improved environmental compatibility, decreased fuel consumption are just some of the advantages of high strength steel applications in motor vehicles. From the aspect of producer of elements of motor vehicles advantages are satisfied workability, good weldability and formability, fewer filler materials required, good cutability, reduced costs and so on. High strength of steels means a higher degree of elements' hardness, so application of high strength steels also improved its wear resistance. Application of high strength steels in mechanical constructions put new significant perspectives in design of motor vehicles, but, also brings some problems that must be solved in process of design.

REFERENCES

[1] David, S. A., Debroy, T., Dupont, J., Koseki, T., Smartt, H.: "Trends in Welding Research", Proceedings of the 7th International Conference, 2007, American Welding Society, USA

[2] EDAG AG: Future Generation Passenger Compartment (FGPC), 2007, Available from http://www.a-sp.org/publications.htm

[3] EDAG AG: FutureSteelVehicle Phase 1 Engineering Report, 2009, Available from: www.worldautosteel.org/Projects/Future-Steel-Vehicle/Phase-1-Results-Phase-2-Launch.aspx

[4] EDAG AG: Phase 2 FutureSteelVehicle Steel Technology Assessment and Design Optimization Engineering Report, 2010, Available from: www.worldautosteel.org/Projects/Future-Steel-Vehicle/FSVInterimReport.aspx

[5] European Committee for Standardization: Eurocode 3

[6] http://media.ford.com , accessed 29. 06. 2012.

[7] http://www.ducker.com , accessed 23. 04. 2012.
[8] http://www.issb.co.uk , accessed 17. 05. 2012.
[9] http://www.ssab.com/en , accessed 25. 06. 2012.
[10] Hyung-Ju, K., McMillan, C., Keoleian, G., Skerlos, S.: “Greenhouse Gas Emissions Payback for Lightweighted Vehicles Using Aluminum and High-Strength Steel”, Journal of Industrial Ecology, Vol. 14, 2007., pages 929–946
[11] Ilić, A., Ivanović, L., Josifović, D., Lazić, V.: “Advantages of high strength steels applications in mechanical constructions”, Machine and industrial design in mechanical engineering - KOD 2012, Proceedings, University of Novi Sad, Faculty of Technical Sciences, Slovak University of Technology in Bratislava, Faculty of Mechanical Engineering, 2012., pages 501-506, ISBN: 978-86-7892-399-9
[12] Ilić, A., Ivanović, L., Josifović, D., Lazić, V.: “Application of high-strength steels in vehicle design”, Innovative Automotive Technology – IAT 2012, Proceedings, University of Ljubljana, Faculty of Mechanical Engineering, 2012., pages 51-58, ISSN: 1408-1679
[13] International Iron & Steel Institute; Committee on Automotive Applications: “Advanced High Strength Steel (AHSS)”, 2006, Version 3. www.autosteel.org
[14] Jevtic, J. , Gligorijević, R., Borak, Dj.: “Materials in automotive engineering”, Machine Design, University of Novi Sad, Faculty of Technical Sciences, 2007., ISSN 1821-1259
[15] Jovanović, M., Lazić, V.: “Welding of high-strength steels: Weldox 700, manual”, Faculty of Mechanical Engineering, Belgrade/Kragujevac, 2008.
[16] Keeler, S.: “Advanced High-Strength Steels Application Guidelines”, 2009, Available from http://www.worldautosteel.org/projects/AHSSGuidelines/AHSS-application-guidelines-version-4.aspx
[17] Kwon, O., Young Lee, K., Sung Kim, G., Geun Chin, K.: „New Trends in Advanced High Strength Steel Developments for Automotive Application”, Journal Materials Science, 2010., pages 136-141, DOI 10.4028/www.scientific.net/MSF.638-642.136
[18] Lazić, V., Adamović, D., Josifović, D., Jovanović, M.: “Consideration of defining the limits of parameters for welding high strength steels”, Proceedings, Faculty of Mechanical Engineering, Kragujevac, 1995., pages 133-140

[1]THE EFFECT OF OPERATION AND DESIGN PARAMETERS ON THE PERFORMANCE OF PEMFC

Elif Eker, Imdat Taymaz

UDC: 621.5

Summary

In this study, a three-dimensional PEM fuel cell model has been developed. It was analysed the effect of different channel width, membrane thickness, operation pressure and operation temperature on performance of PEM fuel cell. Current density was measured on the single cells of parallel flow fields that have 25 cm² active layers, using different values of these parameters. The cell width and the channel height remain constant. The results show that increasing operation pressure and operation temperature increases the current density and increasing channel width while the cell width remains constant decreases the current density. And also it was shown that fuel cell current density clearly increases as decreasing membrane thickness at the results.

Key words: PEM fuel cell, current density, performance parameters

EFEKTI RADNIH I KONSTRUKTIVNIH PARAMETARA NA PARFORMANSE PEM GORIVE ĆELIJE

UDC: 621.5

Rezime
Razvijeni prostorni model PEM gorive ćelije prikazan je u radu. Različite širine kanala, debljine membrane, radni pritisci i temperature su varirane i analiziran je njihov uticaj na performanse gorive PEM ćelije. Gustina struje je merena na jednoj ćeliji paralelnog polja protoka koji ima 25 cm² aktivnog sloja pri različitim konstruktivnim parametrima. Rezultati istraživanja pokazali su da porast radnog pritiska i radne temperature povećava porast gustine struje i povećanje širine kanala, dok je širina ćelije nepromenjena, dovodi do smanjenja gustine struje. Povećanje debljine membrane dovodi smanjenja gostine struje.

Ključne reči: PEMC goriva ćelija, gustina struje, parametri performansi

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THE EFFECT OF OPERATION AND DESIGN PARAMETERS ON THE PERFORMANCE OF PEMFC

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UDC: 621.5

INTRODUCTION

The proton exchange membrane fuel cell (PEMFC) is considered to be a promising power source, especially for transportation and stationary cogeneration applications due to its high efficiency, low operating temperature, high power density, low emission, low noise .In the last decade a great number of researches have been conducted to improve the performance of the PEMFC.

The performance of a PEMFC is affected by many factors such as cell operation temperature, operation pressures, relative humidity, and mass flow rate of feed gases, channel geometries in current collector plate and the characteristics of the membrane. To understand the influences of these factors in PEMFC performance, current distributions in a single cell have been, in general, studied by numerical simulations. In literature, several modelling and experimental work has been investigated in order to understand the effect of these parameters to the fuel cell performance.

He et al. developed a two-dimensional, two-phase, multi-component transport model to investigate the effects of the gas and liquid water hydrodynamics, membrane thickness on the performance of an air cathode of a PEM fuel cell employing an interdigitated gas distributor. [1]

Yann et al. studied the influences of various operating conditions including cathode inlet gas flow rate, cathode inlet humidification temperature and cell temperature on the performance of PEM fuel cells with conventional flow field and interdigitated flow field Experimental results showed that the cell performance is enhanced with increases in cathode inlet gas flow rate, cathode humidification temperature and cell temperature. [2]

Guvenlioglu et al. developed a detailed steady-state, isothermal, two-dimensional model of a proton exchange membrane fuel cell a finite element method was used to solve this multi-component transport model in membrane. The model-predicted fuel cell performance curves were compared with published experimental results. The effects of channel width and bipolar plate shoulder dimensions, porosity, and the relative humidity of the inlet streams on the fuel cell performance were evaluated. It was found that smaller width channels and bipolar plate shoulders were required for high current density operations. [3]

Husar et al. studied experimentally the effects of different operating parameters on the performance of proton exchange membrane fuel cell using pure hydrogen on the anode side and air on the cathode side. Experiments with different fuel cell operating temperatures, different cathode and anode humidification temperatures, different operating pressures, and

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various combinations of these parameters have been carried out. The experimental results were presented in the form of polarization curves. Based on this study it was found that the performance of the fuel cell increases with the increase of pressure due to the increase of the exchange current density and the reactant gas partial pressures. [4]

Passos et al. studied Nafion membranes with the aim at characterizing the effects of the Nafion content, the catalyst loading in the electrode and also of the membrane thickness and gases pressures. They presented a decrease of the membrane thickness favours the fuel cell performance at all ranges of current densities. At high current densities the best fuel cell performance was found for the electrode with 0.35 mg Nafion cm−2. [5]

1. MODEL DESCRIPTION

A complete single cell PEMFC (figure 1) assembly divided into cathode current collector plate, gas diffusion layers , catalyst layers and anode current collector plate, gas diffusion layers , catalyst layers and membrane were constructed in Gambit2.4.6 and proper boundary conditions were introduced. The computational full model of a single fuel cell would require very large computing resources and long times. So the model is therefore limited to one straight flow channel with the active layer (figure 2). Boundary conditions are set as follows: constant mass flow rate at the channel inlet and constant pressure condition at the channel outlet.

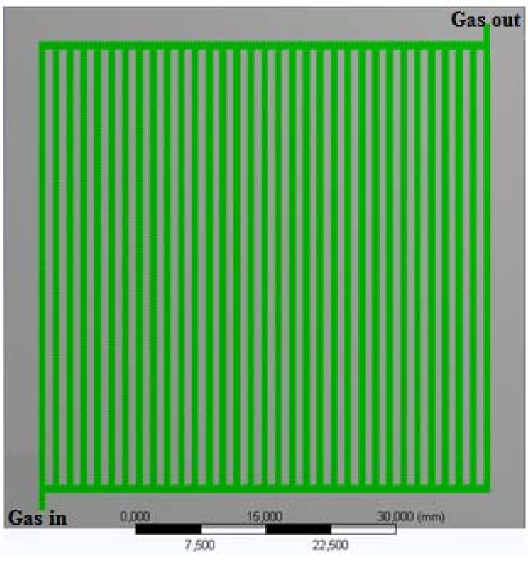

Figure 1 *Current collector plate withstraight channel*

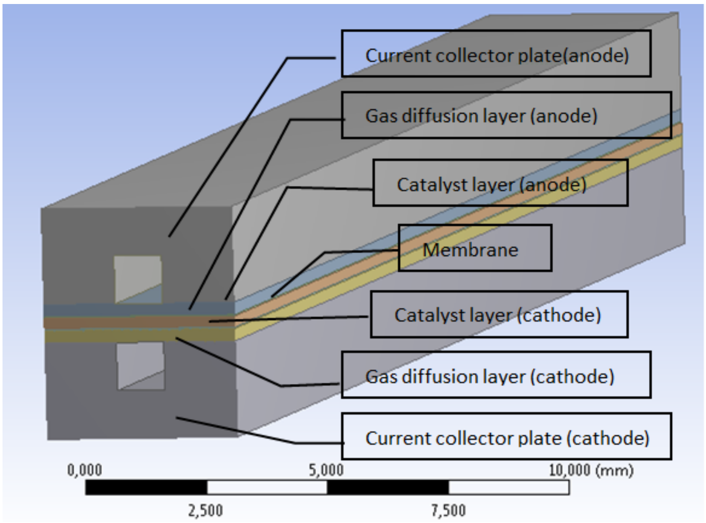

Figure 2 *Schematic view of components of a PEMFC*

2. NUMERIC MODELLING

The below all governing equations and appropriate boundary conditions were solved by using the capabilities of FLUENT 14.0 that employs a finite volume method.

The governing equations for numerical simulation are:

- Conservation of mass,
- Momentum transport,
- Species transport,
- Energy equations.

Conservation of mass equation:

$$\nabla.(\rho\vec{u}) = S_m. \quad (1)$$

The source terms are;

$$S_m = S_{H_2} + S_{wv_p} + S_{wl_p} + S_{awv_e}, \quad (2)$$

$$S_m = S_{O_2} + S_{wv_p} + S_{wl_p} + S_{cwv_e}, \quad (3)$$

$$S_{H_2} = -\frac{M_{H_2} A_{cv} i}{2F}, \quad (4)$$

$$S_{O_2} = -\frac{M_{O_2} A_{cv} i}{4F}. \quad (5)$$

The water vapour at anode and cathode sides is:

$$S_{awv_e} = -\frac{M_{H_2O} \alpha A_{cv} i}{F}, \quad (6)$$

$$S_{cwv_e} = \frac{(1+2\alpha)M_{H_2O}A_{cv}I}{2F}. \quad (7)$$

The change of phases between water vapour and liquid water depends on partial pressure and is defined as:

$$S_{wl_p} = -S_{wv_p} \quad (8)$$

$$= -\frac{M_{H_2O}\Sigma_{n\,of\,v}\frac{mass_{n\,of\,v}}{M_{n\,of\,v}}}{\left(1-\frac{P^{sat}_{H_2O}}{P}\right)}\left[\frac{P^{sat}_{H_2O}-P_{H_2O}}{P}\right].r \quad (9)$$

Momentum transport equation:

$$\nabla.(\rho\vec{u}\vec{u}) = -\nabla P + \nabla.(\mu\nabla\vec{u}) + S_{p,i} \quad (10)$$

Where $S_{p,i}$ is the sink source term for porous media in x, y and z-directions:

$$S_{p,i} = -\left(\sum_{j=1}^{3}\frac{1}{\beta_j}\mu u_j\right) \quad (11)$$

Here β is the permeability.

Species transport equation:

$$\nabla.(\rho m_n\vec{u}) = \nabla.(J_n) + S_s, \quad (12)$$

Here 'n' denotes for H_2, O_2 water vapour and liquid water. The source terms are the same as those of the conservation of mass equation. The diffusion mass flux (J) of species n in n-direction is:

$$J_{\xi,n} = -\rho D_{\xi,n}\frac{\partial m_{\xi,n}}{\partial \xi} \quad (13)$$

Where *n* is the dummy variable for direction *x*, *y* or *z*.

Energy equation:

$$\nabla.(\rho\vec{u}h) = \nabla.(k\nabla T) + S_h \quad (14)$$

The source term *h S* can be obtained by energy losses and heat source by phase change. The heat source from the electrochemical reaction:

$$S_{he} = h_{rxn}\left[\frac{IA_{cv}}{2F}\right] - IV_{cell}A_{cv}, \quad (15)$$

The local current density of the cell is calculated from the open circuit voltage ( ) and the losses;

$$I = \frac{\sigma_m}{t}\{V_{oc} - V_{cell} - \eta\}, \quad (16)$$

Where t is the membrane thickness and is the membrane conductivity and defined as:

$$\sigma_m = \left(0.514 \frac{M_{m,dry}}{\rho_{m,dry}} C_{wa} - 0.326\right) . exp\left(1268\left(\frac{1}{T_0} - \frac{1}{T}\right)\right) \quad (17)$$

3. MODEL ASSUMPTIONS

The present model assumes:

- Ideal gas mixtures,
- Steady-state conditions,
- The flow is laminar,
- System is isothermal,

Isotropic and homogenous electrodes, catalyst layer and membrane.

4. ANALYSIS OF MODEL

In this study, the model presented is a three-dimensional, isothermal, single-phase, steady-state model that resolves coupled transport processes in membrane, catalyst layers, gas diffusion layers and reactant flow channels of a PEM fuel cell. The computational domain (Figure 3) is divided into 94080 cells. Boundary conditions are set as follows: constant mass flow rate at the channel inlet and constant pressure condition at the channel outlet. At the below, geometrical, physical and electrochemical parameters used in study are given in Table 1 and Table 2.

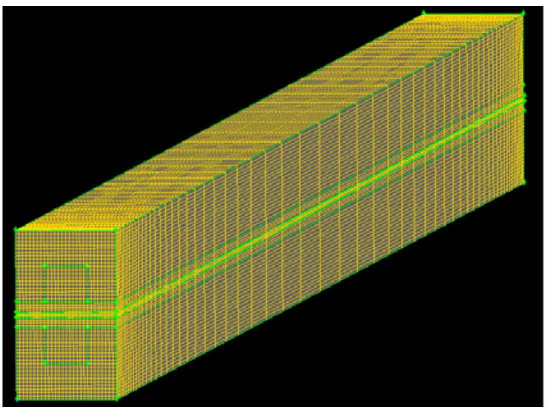

Figure 3 *Fuel cell geometry and computational domain*

Table 1 *Geometrical Parameters*

Parameters	**Value(mm)**
Channel depth	1
Channel width	0.8,1 and 1.2
Channel length	125
Gas diffusion layer thickness	0.27
Catalyst layer thickness	0.02
Membrane thickness	0.127 and 0.051

Table 2 *Physical and Electrochemical Parameters*

Parameters	Value
Gas diffusion layer porosity	0.5
Gas diffusion layer viscose resistance	1e+12 1/m²
Catalyst layer porosity	0.5
Catalyst layer viscose resistance	1e+12 1/m²
Catalyst layer surface /volume ratio	200000 1/m
Reference H_2 diffusion	3e-05 m²/s
Reference O_2 diffusion	3e-05 m²/s
Reference H_2O diffusion	3e-05 m²/s
Anode reference exchange current density	7500 A/ m²
Cathode reference exchange current density	20 A/ m²
Electrolyte area	0.003 m²
Open circuit voltage	0.95 V
Operation pressure	1atm and 2atm
Operation temperature	323K,333K,343K
Cathode mass flow rate	5.0e-6 kg/s
Anode mass flow rate	6.0e-7 kg/s

5. RESULTS AND DISCUSSION

Results are divided into two parts: First, the results observed for operating parameters and the results based on design parameters.

5. 1 *Operation Parameters*

Effect of operation temperature on fuel cell performance

Increasing operation temperature is helpful to enhance electrochemical reaction rate and ionic transport in PEMFC, and the cell performance. However, operation temperature should not be higher than 363 K, or PEMFC may be damaged due to overheating. From the results shown in Figure 4, it is observed that, as the cell temperature increased from 323 K to 343 K, current density increases and the cell performance is enhanced.(channel width is 0.8 mm, pressure is 1 atm and membrane is Nafion 115).

Effect of operation pressure on fuel cell performance

The effects of operation pressure on fuel cell performance are considered for 1atm and 2atm. As can be seen in Figure 5, the current density increases while moving from operation pressure of 1atm to pressure of 2atm. It can be said that operation pressure plays a more important role in fuel cell performance.(channel width is 0.8 mm and membrane is Nafion 115)

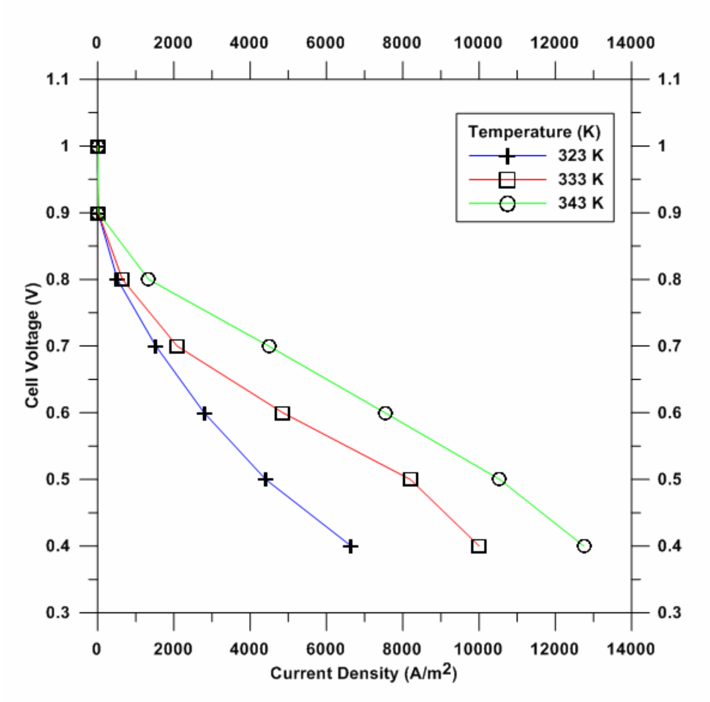

Figure 4 *Operation temperature effect on cell polarization curve*

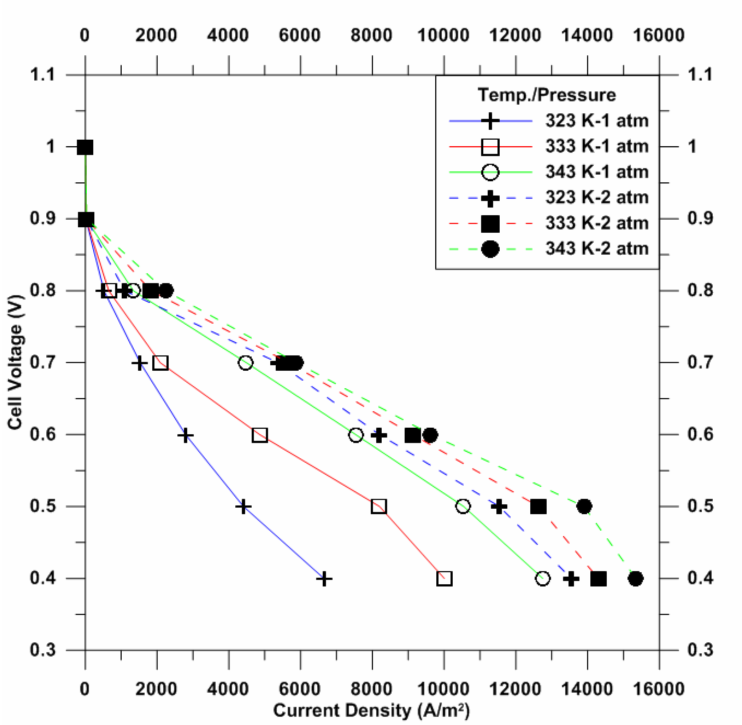

Figure 5 *Operation pressure effect on cell polarization curve*

5. 2 *Design Parameters*

Effect of channel width on fuel cell performance

Analysis of the channel width, in the range of 0.8–1.2 mm, on the fuel cell performance is shown in Figure 6. Operation temperature and pressure are set to be at 333 K and 2 atm. Nafion 115 membrane is used. The effect of channel width on the fuel cell performance becomes more important at high current density applications. It can be seen from Figure 6 that increasing the channel width while the cell width remains constant decreases the current density.

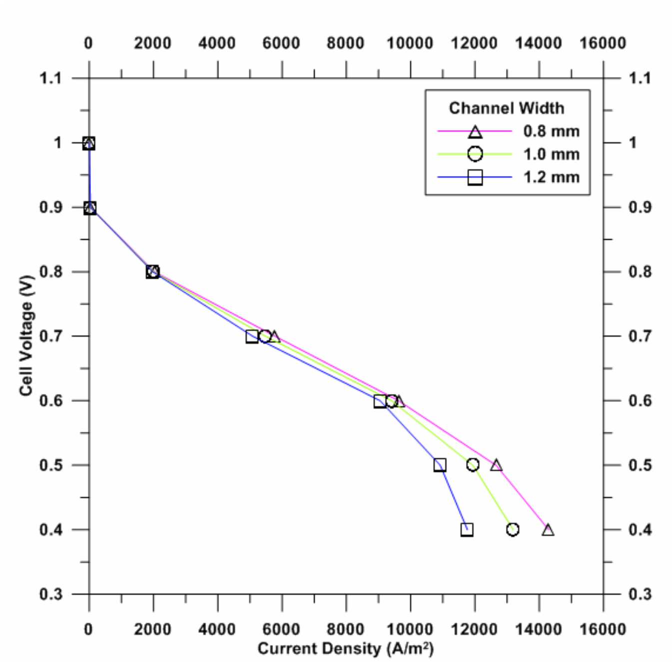

Figure 6 *Channel width effect on cell polarization curve*

Effect of membrane thickness on fuel cell performance

In Figure 7, we investigate the effects of membrane thickness on the current density. As we know, ion conductivity resistance decreases as the membrane thickness decreases and it has no effect on the cell open circuit potential. Operation temperature and pressure are set to be at 333 K and 2 atm. The membrane thickness decreases from 0.127 mm (Nafion 115) to 0.051 mm (Nafion 212). It can be seen from Figure 7 that fuel cell current density clearly increases as decreasing membrane thickness.

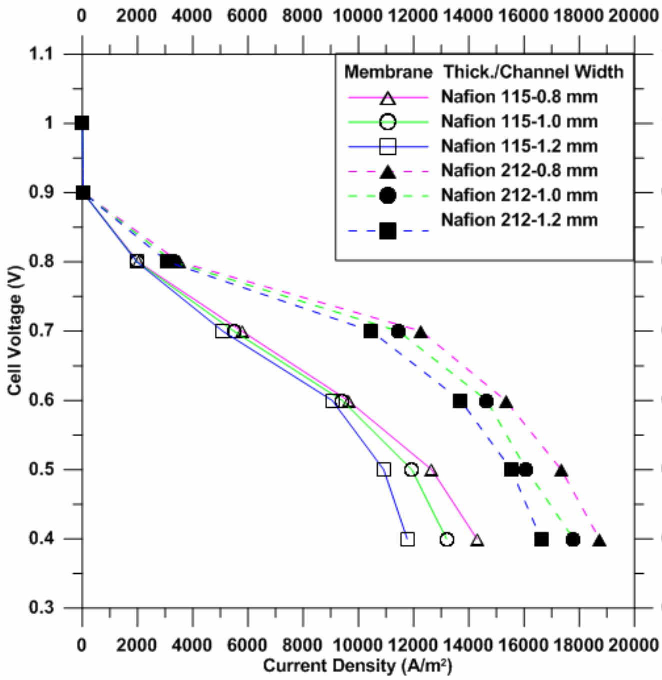

Figure 7 *Membrane thickness effect on cell polarization curve*

6. CONCLUSIONS

Using a single-phase, steady-state, three-dimensional flow simulation of PEM fuel cell, the following conclusion was obtained:

1) Operation temperature is helpful to enhance fuel cell performance. But should not be higher than 363 K, due to overheating of PEMFC.

2) It is found that smaller sized channels (narrow channel width) are required to obtain higher current densities.

3) The membrane thickness has important effect on the polarization curve of the fuel cell. Operation of fuel cell has improved with decreasing its thickness.

7. REFERENCES

[1] He, W., Yi, J.,Nguyen, T.:"Two Phase Flow Model of the Cathode of PEM Fuel Cells Using Interdigitated Flow Fields", AICHE Journal, 46,2000, pp.2053-2064

[2] Yan,M. , Chen,Y. Sheng,M. ,Soong,Y., Chen,F.:" Effects of operating conditions on cell performance of PEM fuel cells with conventional or interdigitated flow field", Journal of Power Sources, 1157-1164,2006,162,pp.

[3] Guvelioglu,G., Stenger,H.: "Computational fluid Dynamics modeling of polymer electrolyte membrane fuel cells", Journal of Power Sources, 147,2005,pp. 95–106

[4] Wang,L. , Husar,A. , Zhou,T. , Liu,H.:"A parametric study of PEM fuel cell

performances” International Journal of Hydrogen Energy, 28,2003,pp. 1263–1272

[5] Passos,R. , Paganin, V. , Ticianelli, E. :“Studies of the performance of PEM fuel cell cathodes with the catalyst layer directly applied on Nafion membranes”, Electrochimica Acta,51,2006,pp.5239-5245.

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