Volume 47, Number 4, 2021.

Mobility & Vehicle Mechanics

International Journal for Vehicle Mechanics, Engines and Transportation Systems

ISSN 1450 - 5304

UDC 621 + 629(05)=802.0

UNIVERSITY OF KRAGUJEVAC, FACULTY OF ENGINEERING

SERBIAN SOCIETY OF AUTOMOTIVE ENGINEERS

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

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For Publisher: Prof. dr Dobrica Milovanović, dean, University of Kragujevac, Faculty of Engineering

Publishing of this Journal is financially supported from:
Ministry of Education, Science and Technological Development, Republic Serbia

Mobility & **V**ehicle **M**echanics

Volume 47
Number 4
2021.

Motorna **V**ozila i **M**otori

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MOBILITY & VEHICLE MECHANICS

DOI: 10.24874/mvm.2021.47.04.01
UDC: 628.4.062

QUANTITATIVE METHODS FOR STEERING KNUCKLE MATERIAL SELECTION

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Received in July 2020 *Revised in August 2020* *Accepted in September 2020*
RESEARCH ARTICLE

ABSTRACT: The paper gives a description of the material selection process for a steering knuckle of a passenger vehicle's independent suspension system, by using two quantitative methods of material selection: Weighted Property Method and Limits on Property Method. After the definition of property requirements that potential materials must meet, digital-logic method has been applied in order to calculate the weighting factors of said properties. The material selection process included the application of Cambridge Engineering Selector for the analysis of diagrams and property values of potential materials. The obtained results indicate that the Weighted Property Method leads to the conclusion that the optimal steering knuckle material is low alloy steel 25CrMo4, while the Limits on Property Method shows that aluminum alloy AlZn5.5MgCu T6 is the optimal material.

KEY WORDS: selection, material, steering knuckle, quantitative methods, independent suspension, CES

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KVANTITATIVNE METODE IZBORA MATERIJALA RUKAVCA

REZIME: Rad predstavlja opis postupka izbora materijala rukavca nezavisnog sistema oslanjanja putničkog vozila pomoću dve kvantitativne metode izbora materijala: metode uticajnosti svojstava i metode graničnih vrednosti svojstava. Nakon definisanja osnovnih kriterijuma, tj. zahteva koje potencijalni materijali moraju ispuniti, za računanje faktora važnosti svojstava je primenjena digitalno-logička metoda. Postupak izbora materijala obuhvatao je primenu softvera *Cambridge Engineering Selector* za analizu dijagrama i vrednosti svojstava potencijalnih materijala. Dobijeni rezultati ukazuju da metoda uticajnosti svojstava dovodi do zaključka da je optimalni materijal rukavca niskolegirani čelik 25CrMo4, dok metoda graničnih svojstava materijala pokazuje da je legura aluminijuma AlZn5.5MgCu T6 optimalni materijal.

KLJUČNE REČI: izbor, materijal, rukavac, kvantitativne metode, nezavisno oslanjanje, CES

QUANTITATIVE METHODS FOR STEERING KNUCKLE MATERIAL SELECTION

Vladica Živković, Dragan Adamović, Bogdan Nedić

INTRODUCTION

Material selection is one of the most important activities in the design process of components of any technical system [1]. The fact that there are more than 70.000 types of materials [2], of which more that 40.000 are metal-based alloys [3] makes the material selection extremely challenging. A large number of available materials, as well as a large number of criteria in the material selection lead to an increase in the complexity and uncertainty in decision making, so it is useful to use quantitative methods [4]. The goal of quantitative methods for material selection is not to replace experience, but to avoid exclusion of some possibilities, as well as to reduce the subjectivity of the process [1]. The material selection started by the ranking the properties of steering knuckle candidate materials depending on the weighting factors, obtained by the digital-logic method. After that, by applying two quantitative methods for material selection, Weighted Property Method and Limits on Property Method, the optimal materials for the steering knuckle of the passenger vehicle's independent suspension system were selected.

1. ENVIRONMENTAL ASPECTS OF THE KZS PROJECT

The suspension system of a passenger vehicle has two basic functions: to maintain the desired position of the wheels in relation to the road surface and the vehicle body, and to receive and transmit generated forces and torques [5]. It is necessary that the suspension system ensures that all four wheels, especially the drive wheels, maintain contact with road surface in all driving conditions. It is of great importance that the suspension system contributes to the decrease of road bumps impact on vehicle, throughout the entire range of vehicle's gear ratios and velocities. Road holding and comfort are essentially opposite requirements, so a compromise between them needs to be reached. There are two types of vehicle suspension systems: dependent and independent. The wheels of the dependent suspension system are placed on a rigid axle, which leads to the direct transmission of the disturbances between the wheels of such an axle, which is undesired. The positive side of this type of suspension system is the constant position of the wheels relative to the road surface. A big disadvantage is large unsprung mass, especially with the drive axle, as well as the relatively large space required for the system mounting. The independent suspension system, unlike the dependent one, allows vertical displacements of a wheel, without it affecting the other wheel of the same axle [7]. Most passenger cars and light trucks are equipped with an independent suspension system on the front axle, as it provides significantly more space for the engine mounting, greater wheel movement, increased vibration resistance, better vehicle handling, and overall better driving comfort. The disadvantage of this system is the complexity of the construction and high production costs, due to the increased number of parts [8, 9]. There are several designs of independent suspension system, of which the most widely used is the system with two control arms of different lengths (Double Wishbone Independent Suspension), shown in Figure 1. The design of the system allows compensation of vehicle body tilting, and keeps the wheels in constant positions relative to the road surface, and provides high vehicle stability [5].

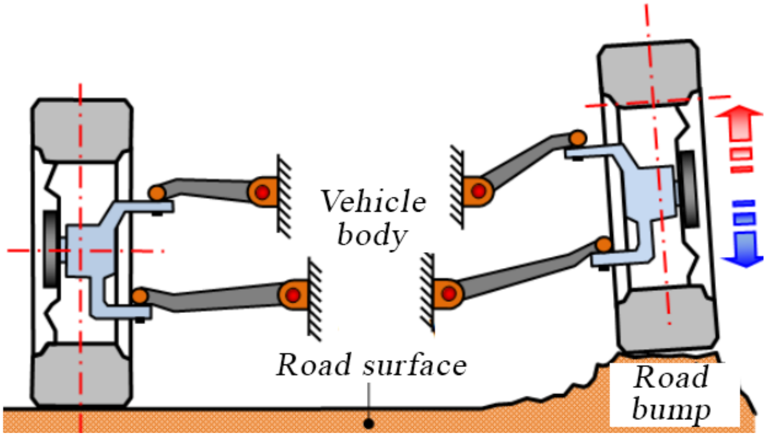

Figure 1 Double Wishbone Independent Suspension [8]

The upper control arms are generally shorter than the lower ones, which directly affects the camber angle values. These suspension systems are commonly known as SLA (Short Long Arms) suspension systems. Control arms are connected to the steering knuckles via ball joints, and to the vehicle body via bushings. Steering knuckle (Figure 2) is one of the most important components of an independent suspension system, and it must be able to withstand loads acting in several directions [10]. These loads include forces due to steering, lateral and longitudinal forces, braking force, inertial force, etc. The steering knuckle provides a link between wheels and the steering system, supports wheel hub and brake caliper, and must provide needed geometrical parameters of drive wheels (camber angle, caster angle, toe pattern, toll center height, scrub radius, turning radius).

Figure 2 Appearance of steering knuckle [11]

Forces and moments present in the vertical loading planes lead to the generation of bending moment in the steering knuckle, while wheel steering and turning lead to torsion moment occurrence. The most advantageous steering knuckle design is the one where the knuckle has a shape of a wheel hub flange, with curved extensions that provide the connection with the ball joints, which accept different working loads, and transfer them to the control arms and tie rod [5]. Steering knuckle can be manufactured by forging, casting or thyxoforming. Taking into account the existing solutions, the influence of characteristics of the mentioned technologies on the geometric accuracy, surface quality, visual appearance and price, it is determined that hot forging is the most favorable manufacturing technology.

2. STEERING KNUCKLE MATERIALS

2.1 Low-carbon steels

Low-carbon steels are very suitable for forging and are relatively low cost, and therefore are commonly used for the manufacturing of some independent suspension system components, such as steering knuckles. The tensile strength of low-carbon steels is not at a very high level, but the ease of forging and low price lead to their wide application.

2.2 Medium-carbon steels

Medium-carbon steels (from 0,3 to 0,5%) are, as a rule, subjected to heat treatment, which reduces residual stresses and improves their ductility. Annealing of medium-carbon steels results in an increase in yield strength and ductility, with a slight decrease in tensile strength and hardness [15].

2.3 Low-alloy steels

Low-alloy steels have better tensile properties compared to low-carbon and medium-carbon steels. Low-alloy steels in which the main alloying elements are chromium and molybdenum (1% Cr; 0,2% Mo) are widely used in the manufacturing of independent suspension system’s components. Chromium alloying is usually done in order to increase corrosion and oxidation resistance, as well as to improve hardenability [16]. Molybdenum alloying up to 0,2% further increases the hardenability of low-alloy steels [17]. Another advantage of Cr-Mo low-alloy steels are good creep characteristics [16].

2.4 Aluminum alloys

Aluminum alloys are used for the production of the components of independent suspension systems primarily for the mass savings that they provide [18]. It is estimated that every 10% savings in vehicle mass leads to a reduction in fuel consumption of 5 to 7% [19]. Reduction of vehicle mass results in decrease of gyroscopic torque, which occurs as a result of simultaneous wheel rotation and turning, and has a negative impact on the vehicle handling characteristics [19]. In addition, the usage of aluminum alloy in fabrication of independent suspension system parts leads to high reliability [20], efficient vibration damping, as well as reduction of vehicle noise, compared to other materials which are used to fabricate the components of an independent suspension system. According to the method of processing, aluminum alloys are divided into casting aluminum alloys and wrought aluminum alloys. They can also be divided into aluminum alloys that can be heat treated, and those that cannot be heat treated. The processing of wrought aluminum alloys is performed by forging on mechanical presses, and the blanks are preheated to temperatures of 400-500 °C.

2.5 Magnesium alloys

Of all the materials used to make the vehicle's independent suspension components, magnesium alloys have the lowest density, 1.74 g/cm3, which makes them 35% lighter than aluminum alloys, and over four times lighter than steel [21]. Magnesium alloys are characterized by good ductility, better noise and vibration damping characteristics compared to aluminum alloys, and excellent casting capabilities [22]. The biggest disadvantage of magnesium alloys is their high cost [23]. However, if the reduction in fuel consumption is taken into account, as well as the lower life cycle costs of components made of magnesium alloys compared to other applied metals [24], exploring the possibility of wider implementation has potential. Another disadvantage of magnesium alloys are poor creep characteristics, which can be removed by using Mg-Al-Si alloys, but casting of these alloys is problematic [25].

3. STEERING KNUCKLE MATERIAL SELECTION

The material selection for the steering knuckle will be made for the case of a medium class passenger vehicle, with a curb weight of approximately 1.500 kg, in which a Double Wishbone Suspension can be used on both the front and rear axle, depending on the vehicle drive concept. In order to compare the results of the usage of two different quantitative methods of material selection, the following methods are applied: Weighted Property Method and Limits on Property Method.

3.1 Weighted Property Method

The Weighted Property Method is of special importance when it is necessary to evaluate a large number of component properties. It consists of essential properties consideration, multiplication of their numerical values by the appropriate Weighting Factor (Bi), which leads to the relative importance of each individual property. By summarizing the properties of materials this way, Performance Index (Vr) of each potential material can be calculated. Determination of Weighting Factor of properties is often greatly influenced by experience, so digital-logic method is applied. By using this method, each property is compared with each, property with a greater importance is given the grade 1, and property with less importance is given the grade 0. For n material requirements (properties), the total number of questions is $n \cdot (n-1)/2$. The Weighting Factor is equal to the ratio of the number of positive decisions for the observed property and the total number of questions [26]. The requirements that need to be met during the steering knuckle material selection are:

1. Maximum flexural strength (σ), which reduces the possibility of fractures of the tie rod-connecting region of the steering knuckle.
2. Maximum elongation (A), which provides a high level of material toughness.
3. Maximum modulus of elasticity (E), because it provides a high level of rigidity, which ensures the transfer of forces and moments without significant deformation.
4. Minimum density (ρ), because it leads to minimization of mass, which is one of the main influencing factors on vehicle fuel consumption.
5. Maximum forgeability (F), because it is determined that hot forging is the desired manufacturing technology. The reason for the choice of forging is mainly greater resistance to cyclic plastic deformations of forged steering knuckles compared to cast ones [27], as well as constant and higher fatigue strength of forged steering knuckles throughout service life, again in comparison with cast ones [27].

6. The minimum price per unit volume (C/m3), in addition to technical criteria, directly defines the competitiveness of products on the market.

Since the number of observed properties is n=6, the total number of questions is 15. The results of the digital-logic method for the steering knuckle material are given in Table 1.

Table 1 *Digital-logic method for the steering knuckle material*

Property	Decision														
σ	1	1	1	0	0										
A	0					1	1	0	0						
E		0				0				0	0	1			
ρ			0				0			1			1	1	
F				1				1			1		0		
C/m^3					1				1			0		0	0

Table 2 shows the calculated values of Weighting Factors for the steering knuckle material properties.

Table 2 *Weighting Factors for the steering knuckle material properties*

Property	Positive decisions (1)	Negative decisions (0)
σ	3	0,20
A	2	0,13
E	1	0,07
ρ	3	0,20
F	4	0,27
C/m^3	2	0,13
Total	15	1,00

In case there are a relatively large number of requirements (properties), with different units of measure, it is necessary to introduce the notion of scaled values of properties (Sv), which make it possible to convert dimensional values into dimensionless values [1]. Depending on the nature of the requirement associated with the observed property, the best value may be the maximum or minimum value in the list [3]. When it comes to the steering knuckle, the minimum values of density and price are required, while in the case of flexural strength, elongation, modulus of elasticity, and forgeability, the maximum values of properties are the required ones. When it is difficult to quantify a property value (i.e. forgeability), the considered property is assigned a value from 1 to 5 [4].

If the minimum value of the property is the best, the expression for the scaled value for a given candidate material is [28]:

$$S_{v_i} = \frac{\text{Numerical value of property}}{\text{Maximum value in the list}} \times 100 \quad (1)$$

and if the maximum value is required from the property, the expression for the scaled value for a given material is [28]:

$$S_{v_i} = \frac{\text{Minimum value in the list}}{\text{Numerical value of property}} \times 100 \qquad (2)$$

The Performance index Vr is used for the ranking of potential materials, and it is expressed as [29]:

$$V_r = \sum_{i=1}^{n} B_i \cdot S_{v_i} \rightarrow \max \qquad (3)$$

Among the low-carbon steels, steel S270GP, which is characterized by good machinability [15], superior deformability compared to other low-carbon steels [30], as well as low price, was selected. Among the medium-carbon steel, C35 steel was chosen, because it is highly forgeable and has been used in the automotive industry for many years to make components of an independent vehicle suspension system [30]. As an ideal material from the group of low-alloy steels, steel 25CrMo4, which is characterized by good tensile and fatigue characteristics, as well as high impact resistance [15], was chosen. Al-Zn-Mg-Cu aluminum alloys were taken into account, due to the favorable combination of strength and susceptibility to heat treatment [31]. Among them, the AlZn5.5MgCu was chosen due to its good tensile characteristics, low density and high corrosion resistance [31]. Heat treatment of this alloy within the T6 regime leads to a significant improvement of its mechanical characteristics [31]. When it comes to magnesium alloys, the most suitable are Mg-Al-Zn alloys, among which the MgAl8Zn, heat treated within the T5 regime was selected. T5 heat treatment regime results in the highest possible strengthening of said alloy [31]. The mentioned alloy is characterized by better tensile characteristics than other Mg-Al-Zn alloys, as well as excellent corrosion resistance [31]. Based on the values of the properties of candidate materials for steering knuckle (table 3), acquired from the Cambridge Engineering Selector (CES) software, which uses data from manufacturers, textbooks, websites, standards, as well as various databases and expert systems, corresponding Performance Indexes were calculated (table 4).

Table 3 *Properties of candidate materials for steering knuckle*

Material	Property					
	σ	A	E	ρ	F	C/m^3
S270GP	274	30	210	7,85	4	3,61
C35	320	27	210	7,85	5	3,69
25CrMo4	400	28	210	7,85	5	3,77
AlZn5.5MgCu T6	500	8	73	2,81	4	6,24
MgAl8Zn T5	205	6	45	1,80	5	5,58

***Table 4** Performance Indexes of candidate materials for steering knuckle*

Material group	Material	Vr	Rank
Low-carbon steel	S270GP[1]	70,2	3
Medium-carbon steel	C35[1]	75,8	2
Low-alloy steel	25CrMo4[1]	79,1	1
Aluminum alloy	AlZn5.5MgCu[2] T6	67,7	4
Magnesium alloy	MgAl8Zn[3] T5	67,6	5

The highest value of Performance Index has low-alloy steel 25CrMo4, hardened at a temperature of 865 °C, and medium-carbon steel C35, in the annealed state. They are followed by annealed low-carbon steel S270GP, aluminum alloy AlZn5.5MgCu T6 and magnesium alloy MgAl8Zn T5. Based on this, it follows that by using the Weighted Property Method low-alloy steel 25CrMo4, hardened at a temperature of 865 °C, is chosen as the material for the steering knuckle of the independent suspension system. The mentioned material is characterized by a good combination of strength, ductility and fatigue strength. The recommended forging temperature of this steel is 1205 °C [33].

3.2 Limits on Property Method

Limits on Property Method quantitative method of material selection is based on the mapping of the material requirements into the limit values of material properties, more precisely: lower-limit values of properties, upper-limit values of properties and target values of properties [34]. Whether a lower-limit, upper-limit or target value will be set for a certain property depends on the requirements posed on a certain property [34]. Within the Limits on Property Method, a quantitative comparison of materials is performed according to the value of the Figure of Merit M, for each of the candidate materials, according to the expression [34]:

$$M = \left[\sum_{i=1}^{n_d} B_i \frac{Y_i}{X_i}\right]_d \cdot \left[\sum_{j=1}^{n_g} B_j \frac{X_j}{Y_j}\right]_g \cdot \left[\sum_{k=1}^{n_c} B_i \left|\left(\frac{Y_k}{X_k}\right) - 1\right|\right]_c \rightarrow \min \quad (4)$$

where:

- d, g and c are the lower-limit, upper-limit, and target value properties, respectively.
- n_d, n_g and n_c are the numbers of lower-limit, upper-limit, and target value properties, respectively.
- B_i, B_j and B_k are the weighting factors for the lower-limit, upper-limit, and target value properties, respectively.
- X_i, X_j and X_k are the candidate material lower-limit, upper-limit, and target value properties, respectively.

[1] *Designation accoring to standard EN10025:2019.*
[2] *Designation accoring to standard EN 573-2:1994.*
[3] *Designation accoring to standard ISO 3116:2019.*

- Y_i, Y_j and Y_k are the specified lower limits, upper limits, and target values, respectively.

Table 5 shows the Limit Values of properties, as well as Weighting Factors of the properties for the steering knuckle candidate materials, which were calculated in the previous part of the paper, by using the digital-logic method.

Table 5 *Limit values and weighting values of candidate materials for steering knuckle*

Property	Limit value	Weighting factor Bi
σ	Lower Yi = 200 [MPa]	0,20
A	Target Yk = 15 [%]	0,13
E	Lower Yi = 45 [GPa]	0,06
ρ	Target Yk = 3 [kg/m3]	0,20
F	Target Yk = 5 [-]	0,27
C/m3	Upper Yj = 6,5 [€/m3]	0,13

Based on the Limit Values of the properties, the Figures of Merit of the candidates for the steering knuckle material were calculated, as it is shown in Table 6.

Table 6 *Figures of Merit of candidates for the material of the steering knuckle*

Material	M	Rank
S270GP	0,67	3
C35	0,69	4
25CrMo4	0,66	2
AlZn5.5MgCu T6	0,47	1
MgAl8Zn T5	0,88	5

Limit on Values quantitative method of material selection indicates that the optimal material for the steering knuckle of an independent suspension system is aluminum alloy AlZn5.5MgCu T6.

4. CONCLUSIONS

Making the right decision when in comes to selecting the materials is of great importance during the design process of responsible components. A large number of available materials, as well as a large number of requirements lead to material selection complexity, so it is useful to apply certain quantitative methods of material selection. Within these methods, numerous values of material properties are used in the form of measured or estimated values. The material selection of the independent suspension system of passenger vehicle's steering knuckle was done by applying two quantitative methods of material selection: the Weighted Property Method and the Limits of Property Method. Using the first method, low-alloy steel 25CrMo4 was chosen as the optimal material for the steering knuckle, as the material with the highest value of Performance Index. According to the second method, aluminum alloy AlZn5.5MgCu, heat treated within the T6 regime, was chosen for the steering knuckle material. Based on the comparison of the results of application of different quantitative methods of material selection, it follows that the Limits of Property Method gives preference to aluminum alloys, primarily due to high flexural strength and low density, which are, in addition to forgeability, one of the most important properties of independent suspensions' steering knuckle material.

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MOBILITY & VEHICLE MECHANICS

DOI: 10.24874/mvm.2021.47.04.02
UDC: 62 592.3

A CONTRIBUTION TO THE DEVELOPMENT OF AUTOMOTIVE MAGNETORHEOLOGICAL BRAKE

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Received in July 2020 *Revised in August 2020* *Accepted in September 2020*

RESEARCH ARTICLE

ABSTRACT: The main challenges in automotive brake design are maintenance, response time, and braking torque. This paper is a part of the ongoing research that deals with the feasibility of incorporating magnetorheological type brake into the automotive size wheel. Materials, whose rheological properties change reversibly under the influence of an external force, belong to a group called smart materials. This group includes fluids, greases, gels, polymers etc. Materials whose rheological properties change under the influence of an external magnetic field are called magnetorheological materials. Magnetorheological grease is a type of material whose rheological properties also change due to an external magnetic field influence. The main disadvantages of any magnetorheological system are insufficient torque and/or settling effect. Increasing the magnetorheological brake`s braking torque by varying the shape and the number of active surfaces in contact with magnetorheological material is the basis of this research. Research partially relies on the results gained from earlier magnetorheological brake model simulations, done in COMSOL Multiphysics. Dealing with the magnetorheological material`s settling effect, with the usage of magnetorheological greases, has been presented. Magnetic flux distribution analysis was carried out in a number of simulations, using the same software. The proposed design shows great potential.

KEY WORDS: brake, magnetorheological grease, settling, finite element method, magnetic flux distribution

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DOPRINOS RAZVOJU AUTOMOBILSKE MAGNETNO-REOLOŠKE KOČNICE

REZIME: Glavni izazovi u dizajnu automobilskih kočnica su održavanje, vreme odziva i kočni moment. Ovaj rad je deo tekućeg istraživanja koje se bavi mogućnostima izvođenja ugradnje magnetno-reološke kočnice veličine točka u automobile Materijali, čija se reološka svojstva reverzibilno menjaju pod uticajem spoljne sile, pripadaju grupi pametnih materijala. U ovu grupu spadaju tečnosti, masti, gelovi, polimeri itd. Materijali čija se reološka svojstva menjaju pod uticajem spoljašnjeg magnetnog polja nazivaju se magnetno-reološki materijali. Magnetno-reološka mast je vrsta materijala čija se reološka svojstva takođe menjaju usled uticaja spoljašnjeg magnetnog polja. Glavni nedostaci bilo kog magnetno-reološkog sistema su nedovoljan obrtni moment i/ili efekat taloženja. Povećanje kočonog momenta magnetno-reološke kočnice promenom oblika i broja aktivnih površina u dodiru sa magnetno-reološkim materijalom osnova je ovog istraživanja. Istraživanje se delimično oslanja na rezultate dobijene ranijim simulacijama magnetno-reološkog modela kočnica, urađenim u COMSOL Multiphysics. Prikazana je analiza efekta taloženja magnetno-reološkog materijala primenom magnetno-reoloških masti. Analiza raspodele magnetnog toka izvedena je u brojnim simulacijama, primenom istog programskog paketa. Predloženi dizajn pokazuje veliki potencijal.

KLJUČNE REČI: kočnica, magnetno-reološka mast, taloženje, metoda konačnih elemenata, raspodela magnetnog fluksa

A CONTRIBUTION TO THE DEVELOPMENT OF AUTOMOTIVE MAGNETORHEOLOGICAL BRAKE

Aleksandar Poznić, Boris Stojić

INTRODUCTION

In the last two decades, magnetorheological - MR materials and devices have gained great attention from researchers mainly because of their controllable properties and potential applications in various fields such as the automotive industry, the civil engineering, and the military sector [1]. Magnetorheological brake - MRB is a type of electromechanical brake that is comprised of a stator, rotor, working medium, and one or more excitation coils. Magnetorheological fluids - MRFs or magnetorheological greases - MRGs, are examples of working mediums that are commonly [1, 2] used in MRB design. The working medium of the MRB is contained between the stator and the rotor. The coils, when excited by the control current, generate magnetic fields that are each directed toward MR working medium through MRB`s body. Affected by the magnetic field, the MR medium`s viscosity changes [1-4]. Change in viscosity leads to a shift in rotational resistance between MRB`s stator and rotor thus increase in the overall braking torque value. Typical MRB is composed of magnetic and nonmagnetic materials. MR working medium is a magnetic material. Its magnetic properties can easily be obtained from its manufacturers. Nonmagnetic materials, such as aluminum, have known magnetic properties. On the other hand, magnetic properties of material such as construction steel, usually are not known or are not freely available, and need to be determined by measurements, [5]. The most important material's magnetic property, in this case, is the highly nonlinear initial magnetization curve, [5]. The major issues with any MRB`s application are viscosity level, solid-phase settling, and the overall braking torque value. There are several ways to overcome these issues. The first step is to use high viscosity, low setting rate MR working medium. Secondly, if possible, to further reduce MR working medium gap size inside the device and to increase the applied magnetic flux acting on the MR working medium. The last one is to enhance the area of the active surfaces in contact with the MR working medium by increasing their heights and by multiplying their number.

The objective of this work was to simulate magnetic flux distribution through MRG layers of an innovative MRB type. MRG layers are constant in gap size - thickness but vary in heights. Particular magnetic flux distribution influence on each MRG layer was analyzed using a commercial Finite Element Method - FEM software. Simplification of the MRB FEM Model and the uniform magnetic flux distribution throughout all MRG layers were primal goals of the simulation. Obtained magnetic flux values were converted into braking torque values, using a predetermine mathematical model, for each layer.

1. MAGNETORHEOLOGICAL BRAKE DESIGN

The authors of this paper have used a hybrid MRB design. It combines known [6] Drum and T-shape rotor brake type design. The new design relies on variations on each of the two types.

1.1 Innovative design

Illustrations in Figures 1 a)-c) are of new MRB design, its cross-section with emphasis on the MRG layers, and segment the multi-T-rotor assembly, respectively. Presented MRB is a design variation of the Drum and the T-shape rotor design. Opposed to the Drum brake type, that only has one coil, or to the T-shaped rotor brake, that has two separate coils, this design has eight individual stationary coils, thus forming a multi-pole structure. These eight excitation coils are divided into two groups. The first coil group is radially arranged on the circumference of an MRB`s stator. The second group, the parallel coils, is positioned parallel to the rotor`s shaft axis, Figure 1, a) and partially b). Each radial coil`s magnetic flux vector is directed towards the center of the MRB, for combined effect increase in the overall magnetic flux intensity - $\vec{B}$, acting on the MRG layers equidistantly arranged inside the brake. Both parallel coil’s $\vec{B}$ are directed opposite to each other i.e. outwards, away from the center of the MRB.

To increase the total MRG active surface area, the T-rotor element was concentrically multiplied several times inwards, thus forming a multi-T-rotor element, Figure 1 c). The proposed MRB multi-T-rotor assembly, i.e. shaft and multi-T element, is composed of both nonmagnetic and magnetic materials. The nonmagnetic shaft also features a nonmagnetic disk, designated as multi-T-element inner support. To have a closed magnetic circuit, two six-spoke magnetic flux return bridges were added, Figure 1, a) and partially b). The magnetic flux spreading pattern is illustrated latter in text in Figure 5.

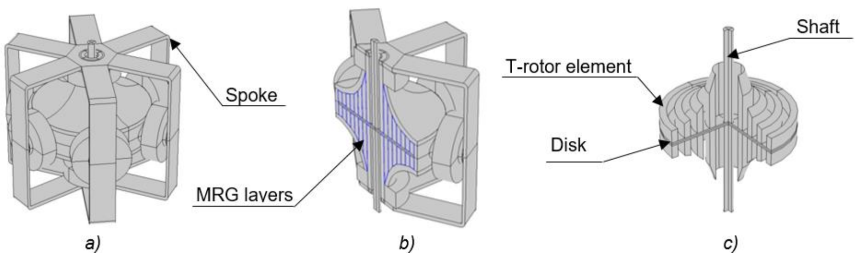

Figure 1 Magnetorheological multi-pole multi-T-rotor brake model, a) innovative design, b) cross-section of the model with an emphasis on active surfaces, c) segmental representation of the multi-T-rotor assembly

1.2 Material properties

The main property of ferromagnetic materials is their magnetic hysteresis loop or initial magnetization curve [5]. This phenomenon is illustrated in Figure 2 a) and b). Ferromagnetic materials, with small hysteresis loop area - magnetically soft materials, are suitable for electromagnets production. On the other hand materials with large hysteresis loop area - magnetically hard materials, are better suited for permanent magnets production, Figure 2 a). Rule of the thumb is that body of the MRB should be made of magnetically soft steel, because of the residual magnetic induction influence.

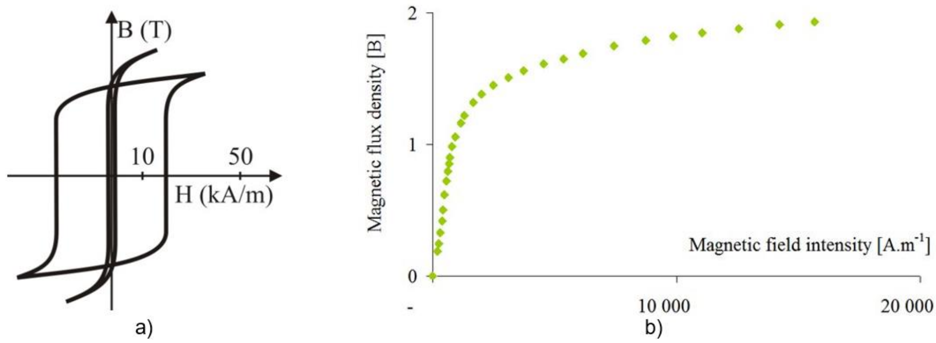

Figure 2 a) Hysteresis loops of magnetically soft steel (small hysteresis loop area) and magnetically hard steel (large hysteresis loop area) [5], b) AISI 1018 B-H curve [8]

To be able to analytically determine the MRB output torque range, one needs to know the magnetic properties of both the construction steel and MRG in use. As mentioned earlier, the magnetic characteristics of all ferromagnetic materials are not regularly available, so the Authors decided for AISI 1018 steel with known magnetic characteristics. The magnetic field versus magnetic flux density relationship of AISI 1018 is presented in Figure 2 b). The main problem with liquid-based MR working medium is the so-called solid phase settling. This phenomenon leads to the reduction of the MR effect and limits the long-lasting usability of the MRF as a working medium. This is especially important in applications such as automotive brakes/clutches because it can lead to device improper operation. The settling occurs due to the mismatch of densities of the liquid base MRF and its CI particle. Compared to the MRF, the unique behavior of MRG is that it does not allow a flow of the magnetic CI particles without the presence of external force, (performs as non-Newtonian fluids at both off-state and on-state conditions), [2]. Based on this, it can be presumed that the grease is better suited for MR devices applications, best of all to eliminate the settling problem. The soft magnetic carbonyl iron - CI particle weight fraction in MRG has a significant impact on its magnetic properties. The larger this percentage is, the higher the magnetization is. Based on this, an MRG with 70 wt% soft magnetic CI particle concentration [3] was selected as a working medium in this FEM simulation. Another problem, that occurs in exploitation conditions, is MR device leakage. The high viscosity of synthetic or mineral oil in MRF requires appropriate sealing to inhibit device leakage, and may indirectly lead to device failure or degradation of its performances. On the other hand, it should be mentioned that the greases are known to have self-sealing properties, to be robust at extreme temperatures and pressures, and have anti-wear properties as well as friction reduction properties in a lubrication role.

2. NUMERICAL SIMULATIONS

The proposed MRB design was modeled using commercial FEM software, COMSOL Multiphysics [7]. Due to the presence of the nonmagnetic disk and two six-spoke magnetic flux density return bridges, Figure 1 a), COMSOL`s 3D space dimension option was utilized. The magnetic field was considered to be static, so the Stationary Study was used. To reduce the required computation power the Model was simplified to a twelfth the volume of the original Model, Figure 3 a). The entire model was surrounded by a sphere-shaped air boundary, several times the volume of the Model. Appropriate material nodes and boundary conditions were assigned to every element of the Model. In this specific simulation, materials such as nonmagnetic air and aluminium were selected from COMSOL's database, but nonlinear magnetic materials, such as AISI 1018 steel and MRG with 70 wt. %, were manually defined. These data have been loaded to the COMSOL as separate files. Note, presence of elements such as ball bearings were neglected because of their steel composition and small volume share in the overall construction. In the Magnetic Fields subsection of the model, additional Ampère’s Laws were needed, due to the use of several different materials. In the same subsection, only three Multi-Turn Coil domain nodes were added due to the axial symmetry cut implemented in this Model. Mesh, Figure 3 b), was generated using the User-controlled mesh. The MRG's layers were meshed using the Free tetrahedral with custom element size. Also, special attention was placed on the curvatures and the narrow regions of MRG segments of the brake. The curvature radii were multiplied by the Curvature factor parameter which in return. gives the maximum allowed element size along a specific boundary. The Resolution of narrow regions parameter controls the number of elements created in narrow regions. These parameters greatly improved the mash quality of the models, which is now at the threshold of 0.1, which is considered a satisfactory mesh. The solver was stationary but non-linear.

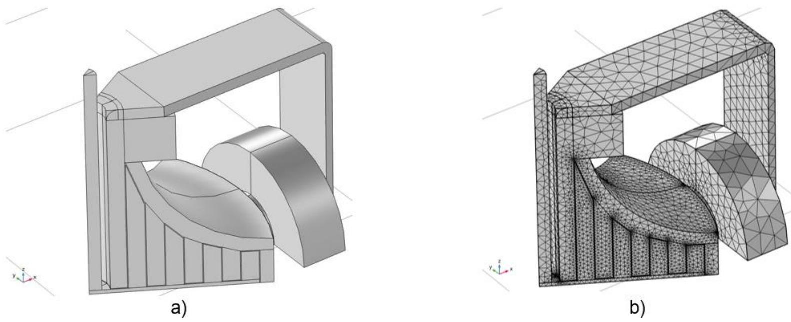

Figure 3 Proposed magnetorheological multi-pole multi-T-rotor brake’s a) simplified Model and b) Model’s mesh

To determine the overall magnetic flux intensity in a specific MRG layer FEM simulation was carried out. A median magnetic flux value was determined along three predetermined circular lines for each MRG layer. Circular lines were positioned at the very top of every MRG layer, in the middle of it, and at the very bottom of it. Illustrations of these lines in the outer MRG layer are presented in Figures 4 a)-c). A 1D Plot Group line graph was used to depicture the magnetic flux magnitude changes along these three circular lines for each MRG layer.

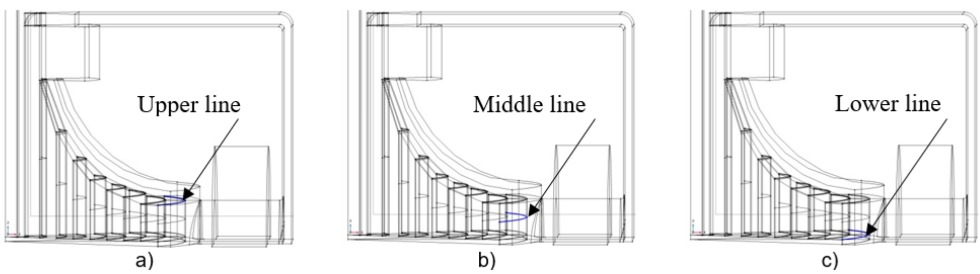

Figure 4 Median magnetic flux value determined along three circular lines, a) Upper b) Middle and c) Lower line of the outer rim MRG layer

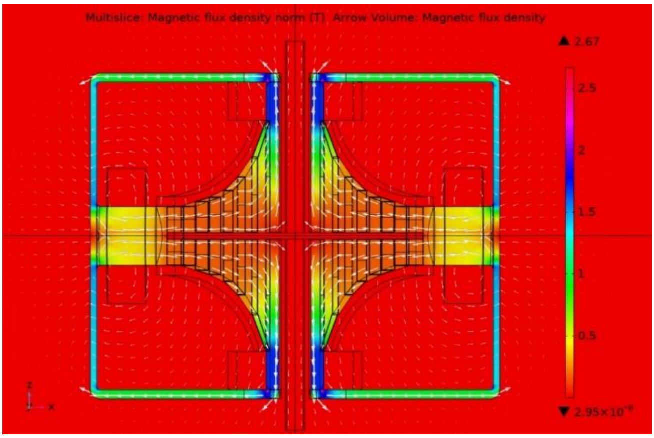

Figure 5 Magnetorheological brake cross-section with magnetic flux spreading routes illustration

Due to the MRB Model's simplification, only two Multi-Turn Coil domain nodes were needed, Figure 6 a). This greatly reduced the required computational power and simulation time. The continuous MRG layers were designed in such a manner that their active surfaces were always perpendicular, as much as possible, to the magnetic flux vector, Figures 5 and 6 b). The hexagonal prism stator, the coils' cores, the multi-T-rotor element, and the six-spoke magnetic flux return bridges, Figure 6 c), were assigned with the magnetically soft steel AISI 1018. The rest of the MRB assembly elements, Figure 6 d), were assigned with nonmagnetic materials. One of these elements is the nonmagnetic disk. The nonmagnetic disk diverts magnetic flux lines spreading route through the body of the MRB, and splits it into two magnetic flux layers, Figure 5. These two layers act uniformly onto separate but geometrically equal segments of the MRG active surfaces. A brief parameter overview of the proposed MRB design is presented in Table 1. The proposed MRB model is planned to be manufactured in the near future.

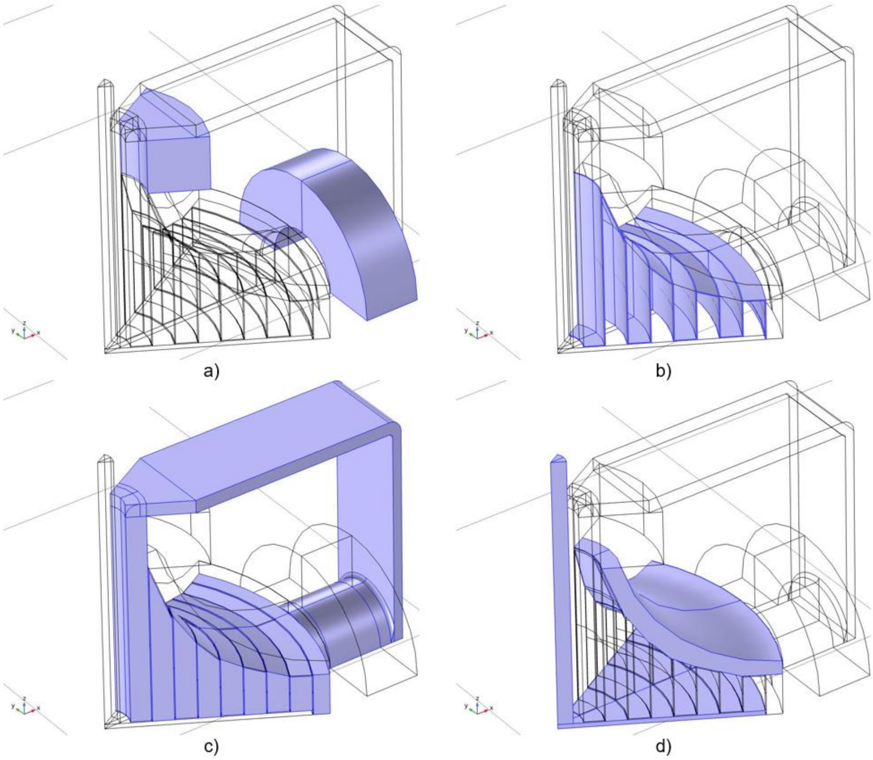

Figure 6 Proposed magnetorheological multi-pole multi-T-rotor brake's elements cross-section illustrations, a) Colis b) MRG layers, c) core and d) nonmagnetic elements of the brake

Table 1 *Multi-pole multi-T-rotor magnetorheological brake parameters*

Parameter	Value
Magnetorheological brakes` outer diameter (mm)	315
Magnetorheological brake`s length (shaft not included) (mm)	127.45
Multi-T-element outer radius (mm)	100
Magnetorheological fluid`s active area height; from - up to (mm)	20.5 - 90.45
Nonmagnetic disks' thickness (mm)	2.5
Nonmagnetic disk radius (mm)	100
Shafts' diameter (mm)	15
Magnetorheological fluid gap (mm)	0.5
Number of coils (-)	8
Maximum control current intensity per coil (A)	100

2.1 Numerical torque modeling

In the case of the multi-T-rotor brake, the torque generating properties can be described by the same analytical model used for the MR drum brake model with the results adjustment for additional MRF layers and their specific radii and heights. The maximum field-induced torque, for MR drum brake, is given by:

$$T_{\tau} = \sum_{1}^{k} 2 \cdot R_{o_k} \cdot \left(2 \cdot \pi \cdot R_{o_k} \cdot l_k\right) \cdot \tau_y = \sum_{1}^{k} 4 \cdot \pi \cdot \tau_y \cdot \left(l_k \cdot R_{o_k}^2\right) \quad (1)$$

Similarly, the maximum viscous torque is:

$$T_{\eta} = \sum_{1}^{k} 4 \cdot \pi \cdot \eta \cdot \frac{\dot{\theta}}{g} \cdot \left(l_k \cdot R_{o_k}^3\right) \quad (2)$$

where, k is the number of MRF layers, R_{ok} is a radius of a specific MRF layer, l_k is the MRG layer`s height, τ_y is the yield stress developed in response to the applied magnetic field, η is the viscosity of the MR fluid with no applied magnetic field, $\dot{\theta}$ is the angular velocity of the rotor and g is the thickness of the MR fluid gap.

It was assumed that the overall intensity of the $\vec{B}$ will increases as it progresses toward inner MRF layers, because of the combining effect of all excitation coils. But the summarization of all excitation coils led to a noticeable decrease of the $\vec{B}$ with the decrease of the R_{o_k}. To exclude this effect, the researchers tried to fix the product of the $\left(l_k \cdot R_{o_k}^2\right)$ to a specific value. This value was determined at the very far radius and the very least height of the MRG layer. The only variable here was the height of the MRF. This has led to a distinctive curvature in T-rotor design, which was not entirely accepted due to manufacturing restrictions. This combination resulted in a different magnetic flux distribution i.e. equal overall torque contribution from each of the MRG layers. Magnetic flux intensity simulations results are presented in this paper.

3. RESULTS AND DISCUSION

3.1 Magnetic flux density distribution

The magnetic flux distribution pattern within the proposed MRB was studied and the results were presented. The average magnetic flux intensity change in each MRG layer compared to layer’s heights is presented in Figure 7. Here a monotonically declining linearity in magnetic flux change through MRG layers is noticeable. This suggests the inconsistency in the field-induced torque values through MRG layers. In Figure 8 a sample of the actual magnetic flux intensity simulation results, generated by a single radial coil, is depicted. The average numerical values for magnetic flux intensity are given in Table 2. These values were determined along three circular lines for each MRG layer. Excellent results repeatability along these lines were achieved. Some inconsistencies in magnetic flux distribution results were present though. The reasons for this lies in the fact that the excitation coils had a radial, periodical arrangement and the MRG layers had a specific shape with progressive heights. But the main reason for the discrepancies between specific layer’s three-line results was their closeness to the MRG/nonmagnetic material boundaries. This led to significant drop in results value for the lower and the upper line compared to the middle line.

Table 2 *Numerical values of magnetic flux intensities at specific radii*

Improved magnetorheological brake design		
Layer	B, [T]	R_{o_k}, [mm]
1	0.0570	22.75
2	0.0545	33.82
3	0.0520	44.89
4	0.0510	55.96
5	0.0500	67.03
6	0.0490	78.10
7	0.0475	89.17
8	0.0450	100.25

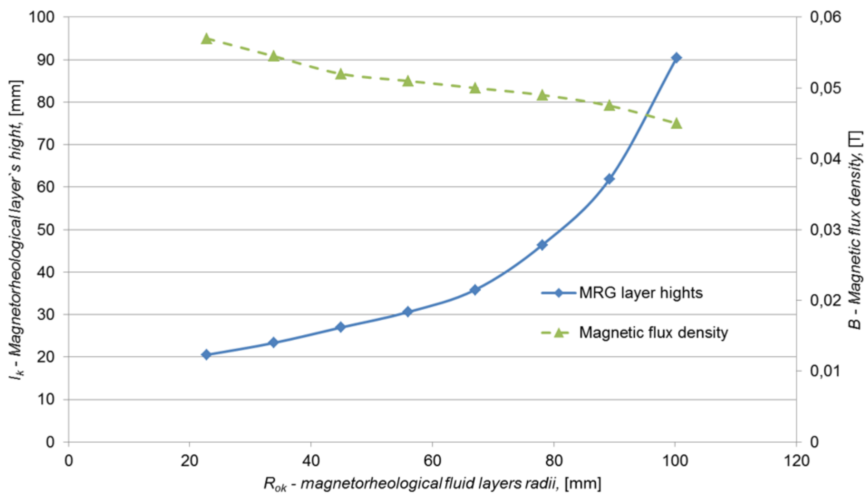

Figure 7 Changes in MRG layer's heights compared to changes in magnetic flux intensity in each MRG layer

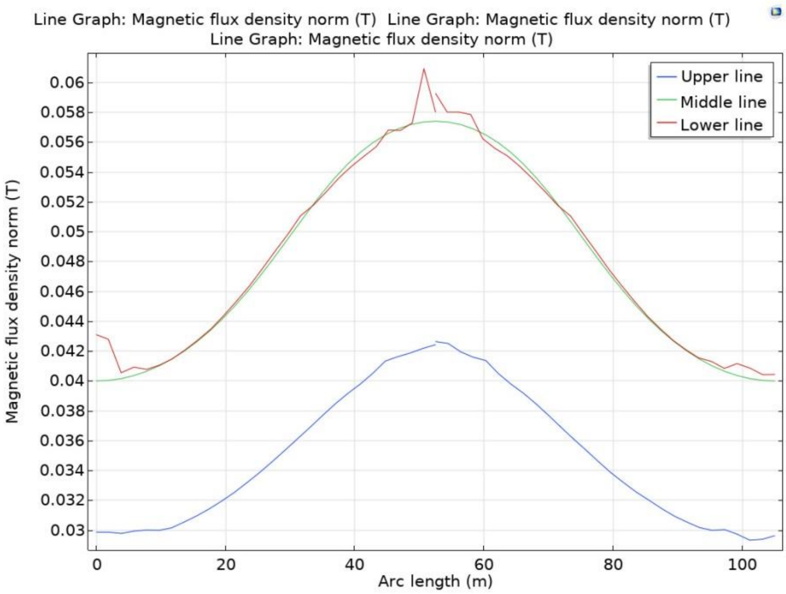

Figure 8 A sample of the magnetic flux simulation results for magnetorheological multi-pole multi-T-rotor brake

4. CONCLUSIONS

This study presented a novel standpoint on magnetorheological brakes design. An improved magnetorheological brake design was introduced. By combining magnetic and non-magnetic materials, a new space may have been opened for magnetorheological technology. The use of non-magnetic material and a specific shape of inner elements lead to magnetic flux unique distribution through MRG layers and MRB's body. The goal of the study was to determine magnetic flux intensity change taking into account the heights of MRG's layers as well. For this purpose, the MRB finite element Model was made using commercial finite element type software. To reduce the required computation power the Model was simplified to a twelfth the volume of the real Model. The Model had the same basic geometry and excitation coils properties. Magnetic flux intensities along specific lines inside magnetorheological grease layers were obtained. Results are presented graphically and tabularly.

A nonlinear relationship between magnetic flux and magnetic field in different materials was applied in the simulations. A combination of materials shapes may contribute to other magnetorheological applications, where there is a need for magnetic flux increase in small areas, but where geometric restrictions are present. It was concluded that the overall magnetic flux density inside MRB decreases with a decrease of the multi-T-rotor radius. This is not favorable in terms of overall torque generation. Further analysis led to the conclusion that the induced torques in MRG layers was not equal and not contributing equally to the overall torque value, thus stressing unfavorably the entire MRB construction.

The proposed multi-pole multi-T-rotor MRB design shows great potential but needs further geometry improvements. Greater braking torque, in constrained volume and weight, is now achievable. Future work should be focused on equalization of the magnetic flux density through magnetorheological grease`s layers which were not the case in this study. This is a part of ongoing MRB Model topology optimization.

ACKNOWLEDGMENTS

This research (paper) has been supported by the Ministry of Education, Science and Technological Development through the project no. 451-03-68/2020-14/200156: “Innovative scientific and artistic research from the FTS (activity) domain”.

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MOBILITY & VEHICLE MECHANICS

DOI: 10.24874/mvm.2021.47.04.03
UDC: 614.75

SOME ASPECTS CONCERNING MANAGEMENT OF ROAD TRANSPORT OF DANGEROUS GOODS USING CONTEMPORARY INFORMATION SYSTEMS

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Received in July 2020 *Revised in September 2020* *Accepted in September 2020*
RESEARCH ARTICLE

ABSTRACT: In this paper, some aspects concerning the management of road transport of dangerous goods using contemporary information systems

for the sake of energy efficiency increase are presented. The prerequisite condition for optimal utilization of available vehicle fleet and improvement of their operational activities in the domain of road transport of dangerous goods is using sophisticated information systems. Compatibility database presented in this paper, as the central and most significant part of the information system, enables and simplifies the first important task in that manner i.e. obtaining the detailed list of dangerous goods that can be transported in the vehicle intended. Besides that, the analysis of the effects of vehicle constructional features variation onto the mentioned list of dangerous goods allowed for transport can be conducted as well. The information obtained from the compatibility database in conjunction with the geographical information system provides the optimal solution to the transport routes.

KEY WORDS: dangerous goods, compatibility database, geographical information system

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NEKI ASPEKTI UPRAVLJANJA DRUMSKIM PREVOZOM OPASNIH TERETA MATERIJA PRIMENOM SAVREMENIH INFORMACIONIH SISTEMA

REZIME: U ovom radu su predstavljeni neki aspekti upravljanja drumskim prevozom opasnih materija korišćenjem savremenih informacionih sistema u cilju povećanja energetske efikasnosti. Preduslov za optimalno korišćenje raspoloživog voznog parka i poboljšanje njihovih operativnih aktivnosti u domenu drumskog prevoza opasnih materija je primena sofisticiranih informacionih sistema. Baza podataka o kompatibilnosti predstavljena u ovom radu, kao centralni i najznačajniji deo informacionog sistema, omogućava i pojednostavljuje na taj način prvi važan zadatak, odnosno dobijanje detaljne liste opasnih materija koje se mogu prevoziti u predviđenom vozilu. Osim toga, može se izvršiti i analiza uticaja varijacija konstruktivnih karakteristika vozila na pomenuti spisak opasnih materija dozvoljenih za transport. Podaci dobijeni iz baze kompatibilnosti zajedno sa geografskim informacionim sistemom pružaju optimalno rešenje za transportne rute.

KLJUČNE REČI: opasne materije, baza kompatibilnosti, geografski informacioni sistem

SOME ASPECTS CONCERNING MANAGEMENT OF ROAD TRANSPORT OF DANGEROUS GOODS USING CONTEMPORARY INFORMATION SYSTEMS

Dragan Vašalić, Zoran Masoničić, Saša Milojević, Ivan Ivković, Radivoje Pešić

INTRODUCTION

Transport and control of transport dangerous goods are very delicate and responsible tasks. Even the smallest mistake can cause catastrophic consequences towards public health and living environment. These issues have been noticed long time ago in all EU countries, so that every union member by using appropriate protocols are achieving dynamic link by amending ADR agreement [1] of road transportation of dangerous goods. Every other year United Nations (ECE) are publishing book with all relevant data of dangerous matters and regulations of transporting each one of them. When it comes to road transportation of dangerous goods, regulations defined in ADR are the first ones to be taken into consideration. ADR defines the very basic requirements for safe transportation of dangerous goods when it comes to road transportation, also as many requests referring to vehicles, goods, classification of goods, compatibility of goods and caring vehicles, ways of packing and analyzing. All of the information includes more than 3,000 dangerous substances that need to be processed during planning and realization of transportation process. These data are part of information system, including compatibility database as the main part which can find its use also in managing transport of dangerous goods. Compatibility database besides the list of dangerous goods also has details of compatibility of dangerous goods with available means of transport based on the aspects of used materials for manufacturing tanks and gaskets. Besides mentioned details, database also contains additional set of information for other constructive characteristics of means of transport. As such, compatibility database gives possibility based on the given requirements, to provide optimal solution, like combination of dangerous goods and carrying vehicles for given transportation route. aing vehicles. Because the carrying vehicles, while doing transportation assignment, get under influence of great number of environmental external factors, but also, they have major influence on life environment, for efficient managing of transportation of dangerous goods, it’s necessary to synchronize: transportation process, as the main process, choosing transportation routes and risk evaluation towards life environment, and their influence on profit increase and energetic efficiency of vehicle fleet. Bearing in mind the above mentioned, in this project, the detailed access of managing dangerous goods transportation by using modern information technology, applying geo-data and base of compatibility will be presented. Using modern information systems, gives higher level managers optimal usage of transportation goods and energetic increase of vehicle fleet efficiency and company as well. It will show detailed activity description, mutually dependent managing levels and necessary compliance of transportation process, which includes, vehicle selection, route selection and their impact on environment based on dangerous goods that's been transported.

1. LITERATURE REVIEW

Need for modification, of ways for managing dangerous goods transportation, with the goal of rationalization and optimization usage of existing vehicle fleet, has been identified long time ago. According to that, based on many authors [2, 3, 4, 5] its necessary to comply the whole process of transportation which includes route planning, risk assessment, motor vehicles, locating vehicles, etc. Important step while managing dangerous goods transportation, besides route planning [6] is maximal usage of transportation capacity [7] which leads to energetic increase of process efficiency. One of the primary process is to obtain dangerous goods compatibility which is transported with transportation goods, so as to say, by using caring vehicles, so that the transportation managing will become efficient and safe with optimal vehicle usage. Many authors claim that for efficient transportation management process, its necessary to synchronize transportation process, which refers to managing, planning and environment process [8,9]. Authors [9] in their research, utilize global information systems with mathematical-analytic planning approach and optimization as a tool to improve managing of dangerous goods transportation and optimal routes selection. Importance of usage modern information systems in route selection especially highlights lower risks of accidents. Authors in research [10] display methodology of managing transportation by using global information system, with the goal to prevent any accidents and emphasize the importance of using modern information systems in selection of the best possible route, to achieve transport managing improvement and risk elimination. By analyzing literature, one can conclude that there are only few related publications, which analyze and combine transportation process, through optimizations of vehicles used – tank vehicles, compatibility between dangerous goods and transporting means and the usage of GIS technologies for achieving the safest and optimal routes.

2. TRANSPORT OPTIMIZATION USING UNIQUE COMPATIBILITY DATABASE

During the planning of transportation process, higher level management in the companies define and plane operational plans of vehicle fleet. Key goals, strategies of the companies are, increase of the company profit, optimization, usage of transformational capacity and reducing the risk of accidents. Based on those strategies, transportation process in road transport of dangerous goods needs to be considered as mutual connection between the driver, vehicle, dangerous goods, road infrastructure, law requirements and environment. In order to accomplish set goals, higher management, based on constructive and exploitation characteristics of caring vehicles, characteristics of dangerous goods and road infrastructure plan daily, weekly and monthly operational work goals, all of that in order to maximize the usage of transportation capacity.

Unavoidable steps during transportation planning are:

- Constructive and exploitation characteristics of available vehicles – characteristics which are directly tied to vehicle for dangerous goods transportation, as possible limitations listed in relevant laws and bylaws. (ADR, Regulation UN ECE R105 [11], etc.).
- Basic, minimal requirements vehicles from aspect of dangerous goods that are going to be transported.
- Set of topographic information relevant for organization of transport (location of loading, offload docks, distance between places, topographic details of the area, number of populated places, throw-out transportation route, etc.).

The most important part of informational system includes of non-eclectic database that consists on compatibility between materials used for manufacturing tanks, gaskets and lining and dangerous substances. This database also includes additional data that allows comparison whether certain substance is compatible with a certain tank, i.e. can it be transported in such a tank vehicle. Compatibility database shows interrelations between materials used for cistern manufacturing (and her components) (8 different tank materials and 22 different gaskets materials) and dangerous goods. In this particular case, within information system of compatibility, the following materials have been taken into consideration.

Table 1 *Tank and gaskets materials used for the purpose of compatibility evaluation*

Tank materials		Gasket and lining materials	
Unalloyed steel	1.0425, P265GH 1.0038, S235JR	PTFE	polytetrafluoroethylene
		FKM	fluoro-rubber, vinylidene-perfluoropropylene-copolymer
		NBR	butadiene-acrylonitrile rubber with 28 % acrylonitrile in the rubber
		NR	natural rubber
CrNi steel	1.4306, X2CrNi19-11	IIR	butyl rubber
		EPD	ethylene-propylene-diene rubber
CrNiMo steel	1.4401, X5CrNiMo17-12-2 1.4404, X2CrNiMo17-12-2 1.4571, X6CrNiMoTi17-12-2	CSM	chlorosulfonated polyethylene
		PE	polyethylene
		PP	polypropylene
		PVC	polyvinyl chloride
		PVDF	polyvinylidene fluoride
		IR	isoprene rubber
		SBR	styrene-butadiene rubber
		CR	chloroprene rubber
Super steels	1.4529, X1NiCrMoCuN25 1.4562, X1NiCrMoCu32-28-7	ACM	acrylate copolymers
		AU	polyester urethane rubber
Nickel-based alloy	2.4605, NiCr23Mo16	Q	silicone rubber
		MFQ	fluorinated silicone rubber
Aluminium	EN AW-1060A Al 99.5%	ECTFE	ethylene chlorotrifluoroethylene
		HNBR	hydrated butadiene-acrylonitrile rubber
Aluminium alloys	EN AW-5083 AlMg4,5Mn	PFA	perfluoro alkoxyl alkane
Zinc	Zinc	PA	polyamide

Besides it, other, very important part of information system is the system containing interrelations between chosen construction parameters of tank vehicles and dangerous goods. This information system contains additional data, which allows comparison whether certain dangerous substance is compatible with certain tank vehicle, so as to say whether it can be transported in such tank vehicle. In addition to the previously listed parts, information system includes set of forms which allow new data entry or possible update of existing and detailed information about them can be found in [13]. Besides them, it's very important to say that information system has capability of data entry about vehicle fleet owned by certain company, with detailed technical description of each vehicle. Basic form used for seraching of corresponding compatibility data can be found on the following picture. On this form, there is possibility of choosing tank material, gaskets material, type of charge and discharge system, the existance of safety valve (for ventilation system, exhaust pipe and burst disk) whether isolation system exists, the maximal substance density, etc. In addition to constructive parameters it includes distinction between tanks used in road transport and transport by sea, because requirements when it comes to tank in these two cases can be very different. Also, it is necessary to distinct between normal (chapter 4.3 and 6.8 in ADR) and portable tanks (chapter 4.2 and 6.7 in ADR). In conditions when transport is handled based on requirements stated in 4.3/6.8, the tank code can be chosen optionally while in case with portable tanks, it has to be handled with portable tank instructions. Tank code is alphanumerical code that describes the type of the tank. Firstly, there is a letter that describes the kind of vessel (L for substances in liquid condition and S for substances in solid condition). Second, there is a numeric value for calculation pressure (G minimal pressure according to general requirements of ADR or 1.25, 2.65, 4, 10, 15 or 21 in bars), Third letter serves for identification of charge and discharge system (A=tank with bottom-filling or bottom-discharge openings with two closures, B= tank with bottom-filling or bottom-discharge openings with three closures, C= tank with bottom-filling or bottom-discharge openings with only cleaning openings below the surface of the liquid and D= tank with bottom-filling or bottom-discharge openings with no openings below the surface of the liquid. On the fourth-place there is letter mark that defines safety valve (V= tank with ventilation system only and no device protecting against propagation of flame, F= tank with ventilation system equipped with device protecting against the propagation of flame, N= tank with safety valve that is not hermetically closed and H= hermetically closed tank).

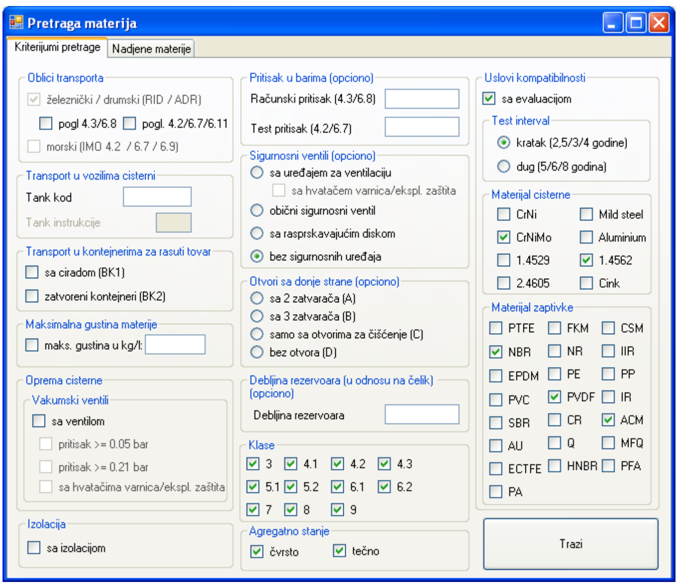

Figure 1 Form used for seraching of corresponding compatibility data

On the following figures search results are displayed. On the Figure 2, there is list of substances which correspond to input criteria, and on the Figure 3, vehicles from database matching the set criterion.

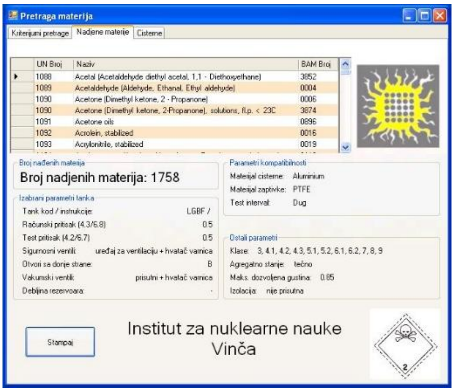

Figure 2 List of substances which correspond search criteria

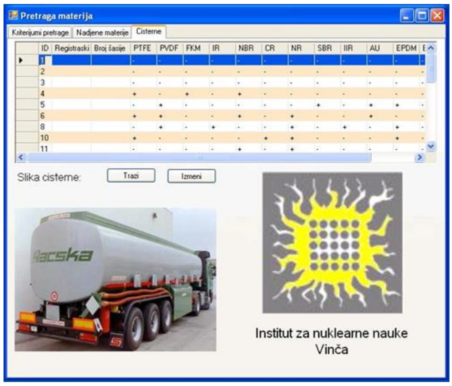

Figure 3 List of vehicles which correspond to search crtieria

Taking into consideration that the essence of energy efficiency of dangerous goods transportation consists from:

- minimalizing the number of vehicles used;
- expansion of the list of dangerous goods that could be transported in available tank vehicles
- using adequate, in particular case original, analysis method avoids incompatibility between materials and substances including the amount of leakages, accidents and negative ecologic effects.
- optimal tank vehicles is chosen for the required dangerous substance.
- optimal modification in case when no appropriate tank vehicle exists.
- optimizing the process of purchasing new vehicles for the given list of dangerous substances intended for the transportation (using analyses of necessary construction parameters and materials for transportation if the dangerous substance considered).

Based on this data, it can be arranged optimization and selection of carrying vehicles for optimal usage of transportation capacity with the final outcome of increasing energy efficiency of the system. For every vehicle in company possession it is possible to gain access of their constructive characteristics, giving centralize managing of companies transportation activities. Based on client's requests, geographical data of loading and unloading docks, the list of dangerous substances transported by companies' vehicles, managers are using database for optimizations and selection of caring vehicles. Dangerous goods transportation from one place to another but with maximum usage of available capacity is complex task, given to managers. Usage of transportation capacity on the way back is additional challenge. It is often necessary to avoid an empty vehicle on the way back, which represents net profit lose, transportation of some other dangerous good is necessary. Using compatibility database with appropriate cartographic support which is given by some of existing modern GIS apps allows multiple time saving and forehand planning and usage of carrying vehicles transportation capacity with simultaneous reducing the risk associated with the transportation process.

3. SDS TEST RESULTS INTERPRETATION

Main requirement for successful a route analyses of the vehicle for dangerous goods transportation is the most accurate implementation of the road infrastructure with surroundings manly because of the fact that risk levels depends from the region that transportation goes through. Using GIS information system in the field of dangerous goods transportation leads to better planning and managing of the transportation process. The geographic information systems [14] are information system which implements work with databases, maps, satellites and air footage and usage of technologies such as GPS – Global positioning system, video mapping, etc. The geographic information system is the system that uses space information, while the reality in it is represented as series of geographic characteristics, which are defined as two groups of elements. First group of elements are the geographical or locational, which are used as the space reference for the second group, attributes or not-locational elements. The principle of operation of the system is such that the data received from vehicles are stored in databases and it allows real time and the space data display to managers of transport. GIS technologies implements regular databases operations such as searching or statistical analyses, with unique advantages of visualization and space analyses that comes with charts. Models used for managing the transportation process of dangerous goods, represents the part of the implemented model for monitoring and management in real time and the space by using modern GIS technology and basis of compatibility. Advantage of the implemented model of managing, reflects through its multifunctionality, based on the fact that it's used for monitoring, coordination and information in the domain of numerous activities during planning of dangerous goods transportation, connected with exploitation of caring vehicles, road infrastructure, loading and offloading docks.

4. CONCLUSIONS

In this paper, the approach for improvement of management of the road transportation of dangerous matter on higher level, using an information system with compatibility database and GIS technology, is presented. Within the implemented transportation management, it has been shown the interrelation between transportation means, like tank vehicles and dangerous goods transported. Possible positive impacts have been displayed towards increase of the energy efficiency by using database of compatibility: optimization of available transporting capacity, minimization of possible occurrence of incompatible combination the tank vehicle – dangerous substance. Besides mentioned improvements, usage of compatibility database has indirect influence on eliminating accidents, and preserving the environment and increasing companies' profit. Further directions of the research will be aimed towards usage of the developed methodology of management, using a basis of compatibility, in other companies in road transportation of dangerous goods, the work monitoring of company and their influence of increasing the energetic efficiency and preserving environment.

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MOBILITY & VEHICLE MECHANICS

DOI: 10.24874/mvm.2021.47.04.04
UDC: 620.97

MEASUREMENT OF RECOVERY ELECTRICITY ON THE E-BUS HIGER KLQ6125GEV3 ON EKO 1 LINE IN BELGRADE AND IMPACT ON ENERGY EFFICIENCY

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Received in July 2020 *Revised in August 2020* *Accepted in September 2020*

RESEARCH ARTICLE

ABSTRACT: One of the most important features of an electric bus (E-bus) is the ability to recover electricity generated during the braking and deceleration phase of the vehicle's movement. The specificity of the bus operation in urban transport is reflected in the dynamic mode of vehicle's operation, especially in terms of frequency and intensity of acceleration and braking. Recovered electricity during the braking and deceleration phase of E-bus drive is determined by the performance of the drive electric motor, the strategy choice (algorithm) for regenerative braking control, driving cycle, terrain configuration, the ability of the supercapacitor to receive as much electricity as possible and the driving style of the driver. The researches of the electricity recovered on the EKO 1 line was performed in 2018 and 2019. The time of year has been chosen when heating and air-conditioning systems were not used or minimally used only in certain periods of the day, in order to more realistically look at the effect of the achieved recovery and the impact on the energy efficiency of the E-bus. The measured values of the supercapacitor voltage, the discharge and recuperation current of the supercapacitor and the SOC (State of Charge) values were taken from the SD memory card BMS (Battery Management System) of the control unit that performs data acquisition from the V-CAN of the E-bus. The value of the recovered electricity, under the assumption that the regenerative braking system is used correctly, is mostly affected by the terrain configuration, i.e. the presence of inclined sections.

KEY WORDS: E-bus, recovered electricity, energy efficiency

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MERENJE OBNOVLJIVE ELEKTRIČNE ENERGIJE NA E-AUTOBUSU HIGERU KLK6125GEV3 NA EKO 1 LINIJI U BEOGRADU I UTICAJ NA ENERGETSKU EFIKASNOST

REZIME: Jedna od najvažnijih karakteristika električnog autobusa (E-bus) je mogućnost regeneracije električne energije proizvedene tokom faze kočenja i usporavanja vozila. Specifičnost rada autobusa u gradskom saobraćaju ogleda se u dinamičkom načinu rada vozila, posebno u pogledu učestalosti i intenziteta ubrzanja i kočenja. Obnovljena električna energija tokom faze kočenja i usporavanja pogona E-autobusa određena je performansama pogonskog elektromotora, izborom strategije (algoritmom) za kontrolu regenerativnog kočenja, ciklusom vožnje, konfiguracijom terena, sposobnošću superkondenzatora da primi što više električne energije i načina vožnje vozača. Istraživanja obnovljive električne energije na liniji EKO 1 vršena su 2018. i 2019. Izabrano je doba godine kada se sistemi grejanja i klimatizacije nisu koristili ili su se minimalno koristili samo u određenim periodima dana, kako bi se realno sagledali efekat postignutog oporavka i uticaj na energetsku efikasnost E-autobusa. Izmerene vrednosti napona superkondenzatora, struje pražnjenja i rekuperacije superkondenzatora i SOC (stanje napunjenosti) preuzete su sa SD memorijske kartice BMS (Sistem za upravljanje baterijom) upravljačke jedinice koja vrši prikupljanje podataka sa V-CAN E-autobusa. Na vrednost obnovljene električne energije, pod pretpostavkom da se sistem regenerativnog kočenja pravilno koristi, najviše utiče konfiguracija terena, odnosno prisustvo deonica pod nagibom.

KLJUČNE REČI: E-autobus, obnovljena električna energija, energetska efikasnost

MEASUREMENT OF RECOVERY ELECTRICITY ON THE E-BUS HIGER KLQ6125GEV3 ON EKO 1 LINE IN BELGRADE AND IMPACT ON ENERGY EFFICIENCY

Slobodan Mišanović, Dragan Taranović, Pavle Krstić, Dušan Živić

INTRODUCTION

The operation of the electric bus drive system is characterized by typical operating modes: vehicle acceleration mode to reach the set vehicle's speed, constant speed driving, and vehicle deceleration and braking mode. Electric and mechanical power flows when the vehicle is in acceleration mode are shown in Figure 1 (a), while the mechanical and electric power flows in braking mode are shown in Figure 1 (b) [1]. An electric generator is an electric drive motor in regenerative braking mode (recuperation).

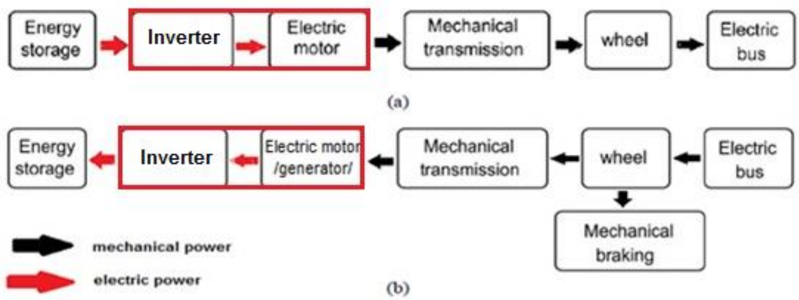

Figure 1 Electrical and mechanical power flows

The required power of the electric motor for the movement of the E-bus and the consumed electricity depends on the load of the vehicle, the resistance forces that occur in the phase of the movement (rolling resistance, grade resistance, aerodynamic and inertial resistance) and speed. The achieved energy recovery in the E-bus in the braking and deceleration phase is determined by the performance of the electric drive, the choice of regenerative braking control strategy (algorithm), driving cycle, terrain configuration, battery/supercapacitor to receive as much current as possible and driving style. According to the recommendations of the vehicle manufacturer "Higer" for the electric bus KLQ6125GEV3, the highest energy recovery in the braking phase and energy efficiency is achieved [2]:

- When the E-bus is moved at speed of about 30÷35 km/h.
- When the drive electric motor operates with the highest efficiency, when the ''rpm'' is above 2000 min^{-1}.
- When the command of service brake is depressed up to 28% of the pedal stroke, because the optimal recovery corresponds to a command angle of 9° (maximum angle is 32°), which represents 28% of the brake pedal stroke.
- When the E-bus moves with a speed higher than 5 km/h, while the engine speed is greater than 600 min^{-1},
- When the deceleration of E-bus is inertial, the braking torque generated by the electric motor has constant value up to 34 Nm and acts on the drive wheels axles.

By reducing the speed of the electric motor to 200 min^{-1}, there is a gradual reduction of braking torque up to a value of 0 Nm.

- Manufacturer of buses ’’Higer’’, states that a better recuperation effect is achieved by activating the service brake up to 28% of the pedal stroke than by decelerating by inertia under the same conditions in terms of achieved speed before direct braking/deceleration by inertia and duration of braking/deceleration by inertia.
- In cases when the service brake is depressed more than 28% of the pedal stroke, the activity is present of regenerative braking on the wheels of the drive axle, and the pneumatic system of the vehicle that acts on the wheels of the steering and drive axles. In this case, it is reduced regenerative braking efficiency.
- When driving downhill, it is recommended applying light pressure on the service brake pedal in order to activate regenerative braking and to maintain a constant speed of movement for the vehicle, thus achieving the best effect of electricity recovery.

The aim of this paper is to investigate the realized recovery energy on the EKO 1 line in real working conditions and the influence of factors, primarily terrain configuration, and driving style.

1. THEORETICAL BASES OF MOVEMENT AND REGENERATIVE BRAKING OF E-BUS

When the E-bus is in acceleration mode, the forces and power are represented by the equations:

$$F_{vu} = F_f + F_v \pm F_u + F_a \quad (1.1)$$

$$P_{mov} = \left(F_f + F_v \pm F_u + F_a\right) \cdot v_{ebus} \quad (1.2)$$

F_{vu} - traction force on drive wheels [N]

F_f - rolling resistance force [N]

F_v - aerodynamic resistance force [N]

grade resistance force (rise, fall) [N]

F_a - inertial resistance force [N]

P_{mov} - required power for the movement of the E-bus [W]

v_{ebus} - speed of E-bus [m/s].

The torque on the drive wheels is shown by equations:

$$\sum_{j=3}^{4} M_{tj} = F_{vu} \cdot r_d \quad (1.3)$$

M_{tj} - the torque on the drive axle wheels [Nm]

$j = 3,4$ - wheels of the drive axle

r_d - dynamic radius of the drive wheel [m].

Electric current flows from the power storage source (battery or supercapacitor) and supplies the drive electric motor via an inverter, which form one unit. From the drive motor, through the transmission to the drive wheels, a flow of mechanical power is generated. These flows are represented by the equations.

$$P_{ucd} \cdot \eta_{uc} = P_{em} \quad (1.4)$$

$$P_{em} \cdot \eta_i \cdot \eta_{em} \cdot \eta_t = \frac{M_{em} \cdot i_t \cdot v_{ebus}}{r_d} \cdot \eta_t = \sum_{j=3}^{4} M_{tj} \cdot \omega_{tj} \quad (1.5)$$

P_{ucd} - storage power for driving of discharge (supercapacitor, battery) during acceleration [W]

P_{em} - the power of the driving electric motor [W]

M_{em} - the torque of the driving electric motor (traction mode) [Nm]

η_{uc} - coefficient of storage efficiency and internal losses

η_{em} - coefficient of efficiency of the driving electric motor (traction mode)

η_i - coefficient of inverter efficiency

η_t - coefficient of transmission efficiency

i_t - total transmission ratio

ω_{tj} - angular velocity of the drive axle wheels [rad/s]

ω_{tj} - angular velocity of the drive axle wheels [rad/s].

Power of the electric motor is proportional to the size of the current and voltage, according to the load and operating modes (acceleration, motion with constant velocity).

$$P_{em} = U_t \cdot I_t \quad (1.6)$$

- current value of electric motor voltage [V]

- current value of electric motor current [A].

The power of electrical losses in the electric motor and inverter depends on the coefficient of efficiency of these two systems is represented by the equation.

$$P_{gem} = P_{ucd} \cdot \eta_{uc} - P_{ucd} \cdot \eta_{uc} \cdot \eta_i \cdot \eta_{em} = P_{ucd} \cdot \eta_{uc} \cdot \left(1 - \eta_i \cdot \eta_{em}\right) \quad (1.7)$$

P_{gem} - power losses of electric motors and inverters [W].

If the operation of the propulsion electric motor is observed in the mode of acceleration of the vehicle or movement at a constant speed in a certain time interval, the consumed electricity can be represented by the equation:

$$E_{em} = \int_{t_1}^{t_2} U_{ti} \cdot I_{ti} \cdot dt \tag{1.8}$$

E_{em} -electricity consumed of driving electric motor [J]
t_1 - start time [s]

t_2 - end time [s].

From the aspect of total engaged electric power: electric motor drive, auxiliary devices, air conditioning and heating systems, as well as losses that occur in the drive electric motor, inverter, battery and electrical installation, it is represented by the equation:

$$P_{ebus} = P_{em} + P_{pu} + P_{ac} + P_h + P_{gem} + P_{gbk} \tag{1.9}$$

P_{ebus} - total engaged power of E-bus [W]

P_{pu} - engaged power auxiliary equipment E-bus [W]

P_{ac} - engaged power of E-bus air conditioning system [W]

P_h - engaged power of the E-bus heating system [W]

P_{gbk} - power losses in supercapacitors (batteries) and E-bus cables [W].

The total power of the drive in equation 1.9, in the time interval, gives the total energy consumed by the E-bus expressed in kWh, which represents the energy consumed from the supercapacitor (battery) in the acceleration phase represented by the equation:

$$E_{p_{uc}} = \frac{1}{3600000 \cdot \eta_{uc}} \int_{t_1}^{t_2} \left(P_{em} + P_{gem} + P_{pu} + P_{ac} + P_h \right) \cdot dt \tag{1.10}$$

$E_{p_{uc}}$ - total electricity consumption of supercapacitors (batteries) in the mode of acceleration [kWh].

When the E-bus is in braking mode, total braking power is shown in the following equation:

$$P_{ki} + P_{kj} + P_{rkj} = \sum_{i=1}^{2} M_{ki} \cdot \omega_{ki} + \sum_{j=3}^{4} M_{kj} \cdot \omega_{kj} + \eta_t \sum_{j=3}^{4} M_{rkj} \cdot \omega_{kj} \tag{1.11}$$

P_{ki} - power of braking wheels on the front axle of the pneumatic system [W]

P_{kj} - power of braking wheels on drive axle from the pneumatic system [W]

P_{rk} - power of braking wheels on drive axle from regenerative braking [W]

M_{ki} - torque of braking wheels of the front axle of the pneumatic system [Nm]

M_{kj} - torque of braking wheels of the drive axle of the pneumatic system [Nm]

M_{rkj} - torque of braking wheels of the drive axle by regenerative braking [Nm]

ω_{ki} - angular velocity of the front axle wheels [rad/s]

ω_{kj} - angular velocity of the drive axle wheels [rad/s]

$i = 1,2$ - wheels of the front axle.

When the E-bus brakes only with regenerative braking ($P_{ki} = P_{kj} = 0$) the mechanical power of the E-bus, which is transmitted to the drive electric motors via drive wheels and transmission, is represented by the equation:

$$\eta_t \sum_{j=3}^{4} \frac{M_{rkj} \cdot v_{ebus} \cdot i_t}{r_d} = P_{rk} \tag{1.12}$$

The electrical power generated by the drive motor is equal to:

$$P_{emg} = \frac{M_{emr} \cdot v_{ebus} \cdot i_t}{r_d} \tag{1.13}$$

So the equation is:

$$\eta_t \sum_{j=3}^{4} \frac{M_{rkj} \cdot v_{ebus} \cdot i_t}{r_d} = \frac{M_{emr} \cdot v_{ebus} \cdot i_t}{r_d} \tag{1.14}$$

P_{emg} - power of electric drive motor in regenerative braking mode (recuperation, generator mode) [W];

M_{emr} - torque of the drive electric motor in regenerative braking mode [Nm].

The power of the electric motor in generator mode represented by the current and voltage has the form:

$$P_{emg} = U_t \cdot I_{tr} \tag{1.15}$$

U_t - current value of electric motor voltage [V];

I_{tr} - current value of electric motor regeneration current [A].

The power of electrical losses in the electric motor and inverter in generator mode can be represented by the equation:

$$P_{gemr} = P_{emg} \cdot (1 - \eta_{emr} \cdot \eta_i) \tag{1.16}$$

P_{gemr} - power losses in the electric motor and inverter in generator mode [W];

η_{emr} - coefficient of efficiency of the driving electric motor in the regenerative braking mode (recuperation).

The output electric power (recuperation power) from the drive electric motor and inverter in the generator mode expressed in terms of current values of current and voltage and losses is shown by the equation:

$$P_{emr} = U_t \cdot I_{tr} \cdot \eta_{emr} \cdot \eta_i \tag{1.17}$$

P_{emr} - output electric power from the drive electric motor and inverter in the generator mode [W].

During regenerative braking in a time interval, the electricity that is generated and that can be stored in the source of electricity storage (supercapacitor, battery) expressed in kWh, is represented by the integral:

$$E_{r_{uc}} = \frac{\eta_{uc}}{3600000} \int_{t_1}^{t_2} \left(P_{emg} - P_{gemr} - P_{pu} - P_{ac} - P_h \right) \cdot dt \tag{1.18}$$

$E_{r_{uc}}$ - recuperation electricity stored in a supercapacitor (battery) [kWh].

The difference between the electricity consumed from the supercapacitor and the energy returned to the supercapacitor in the observation period represents the total electricity consumption of E-bus has the form:

$$\Delta E_{uc} = E_{P_{uc}} - E_{r_{uc}} \tag{1.19}$$

$$\Delta E_{uc} = E_{ebus} \tag{1.20}$$

ΔE_{uc} - difference between the electricity consumed from the supercapacitor and the energy returned to the supercapacitor in the observation period [kWh]

E_{ebus} - total electricity consumption of E-bus in the observation period [kWh].

The efficiency of regenerative braking of electric buses can be expressed as the ratio of electricity generated in the recovery phase to the consumed electricity in the phase of acceleration and driving at a constant speed using the expression.

$$\lambda_{uc} = \frac{E_{r_{uc}}}{E_{p_{uc}}} \cdot 100 \tag{1.21}$$

λ_{uc} - coefficient of efficiency of recovery [%].

If divide the difference between the electricity consumed from the supercapacitor and the energy returned to the supercapacitor in the observation period by the distance travelled by the E-bus, which is usually taken as the length of the route in the direction "A" and the direction "B", the average electricity consumption of the E-bus has the form:

$$\Delta E_{uc_A} = E_{P_{uc_A}} - E_{r_{uc_A}} \tag{1.22}$$

$$\lambda_{uc_A} = \frac{E_{r_{uc_A}}}{E_{p_{uc_A}}} \cdot 100 \quad (1.23)$$

$$\Delta E_{uc_A} = E_{ebus_A} \quad (1.24)$$

$$E_{ebusL_A} = \frac{\Delta E_{uc_A}}{L_A} \quad (1.25)$$

2. METHODOLOGY AND RESULTS OF MEASUREMENT

The research of electricity recovered on the line EKO 1 (Vuk's monument-Belvil) in real operating conditions on a larger sample of measurements in both directions was performed on 25.06.2018, 28.06.2018, 27.09.2018, 08.10. 2019 and 09.10.2019 [2]. The average length of the EKO 1 line is 7995 m. Depending on directions, the length of the route in the direction "A" is 7477 m, where there are 15 stations with an average inter-station distance of 534 m. In the direction "B", the length of the route is 8513 m, where 17 stations are positioned with an average inter-station distance of 532 m. Figure 2, shows the topography of the terrain with the elevations of the stations [3].

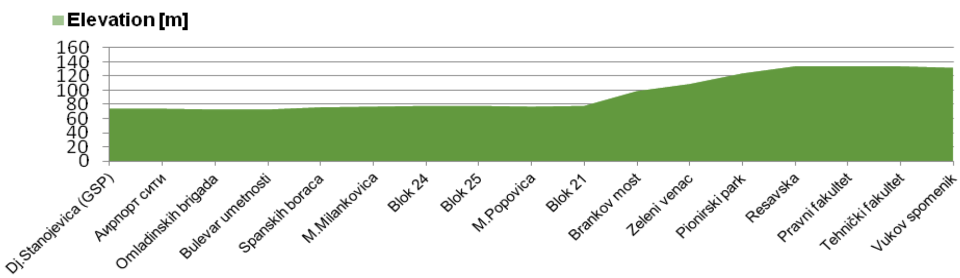

Figure 2 Characteristic of the route line EKO 1

The geometric characteristics of the route of the EKO 1 line are characterized by a distinctly flat terrain configuration in New Belgrade and the distance from the Faculty of Law to Vuk's Monument and a slight ascent of the terrain from Block 21- Branko's Bridge - Brankova-King Alexander Boulevard to Resavska Street. Time of year has been chosen when the heating and air conditioning systems were not used or were used minimally only in some periods of the day when the outside temperatures were higher than 23 ℃ or less than 12 ℃, in order to see as realistically as possible the coefficient of achieved recovery. The measured values of the supercapacitor voltage, current the discharge, the recuperation current of the supercapacitor, and the SOC (State of Charge), values were taken from the SD memory card BMS (Battery Management System) of the control unit that performs data acquisition from the V-CAN bus. The BMS control unit is shown in Figure 3.

Figure 3 BMS control unit

Results of energy consumed from the supercapacitor $E_{p_{ucA}}$, recuperation energy $E_{r_{ucA}}$ returned to the supercapacitor, recuperation coefficient λ_{uc_A}, for the direction "A" (Vuk's Monument – Belvil) is shown in Table 1.

Table 1 *Results of realized recovery energy and consumed energy in the supercapacitor, on line EKO 1, direction "A" (Vuk's monument-Belvil)*

Date [d-m-y]	E-bus	T_{spo} [°C]	Departure time [hh:mm.ss]	Arrival time [hh:mm.ss]
25-06-18	2104	14	7:15:00	7:43:15
25-06-18	2104	16	8:49:04	9:19:32
25-06-18	2104	17	10:23:33	10:50:35
25-06-18	2104	22	13:29:35	13:59:13
28-06-18	2104	17	7:38:08	8:09:40
28-06-18	2104	19	9:12:35	9:40:13
28-06-18	2104	20	10:45:58	11:13:07
28-06-18	2104	22	17:09:20	17:37:42
27-09-18	2105	13	10:22:21	10:50:31
27-09-18	2105	16	13:31:14	14:02:21
27-09-18	2105	18	15:05:21	15:39:43

08-10-19	2103	16	16:12:49	16:45:09
08-10-19	2103	11	19:29:29	20:02:39
09-10-19	2103	21	11:37:36	12:10:30
09-10-19	2103	26	14:39:11	15:12:01
09-10-19	2103	25	16:12:56	16:46:21
09-10-19	2103	13	22:26:16	23:00:31

Table 1 *Results of realized recovery energy and consumed energy in the supercapacitor, on line EKO 1, direction ''A'' (Vuk's monument-Belvil)(continued)*

Driving time [hh:mm.ss]	$E_{p_{uc_A}}$ [kWh]	$E_{r_{uc_A}}$ [kWh]	λ_{uc_A} [%]	ΔE_{uc_A} [kWh]	$E_{ebus_{L_A}}$ [kWh/km]
0:28:15	9.150	2.040	22.30	7.110	0.952
0:30:28	8.220	1.780	21.65	6.440	0.862
0:27:02	7.948	1.915	24.09	6.033	0.808
0:29:38	10.075	2.066	20.51	8.009	1.072
0:31:32	9.716	2.255	23.21	7.461	0.999
0:27:41	9.433	2.693	28.55	6.740	0.902
0:27:09	8.925	2.435	27.28	6.490	0.869
0:28:22	11.302	2.285	20.22	9.017	1.207
0:28:10	9.163	2.593	28.30	6.570	0.880
0:31:07	8.956	2.387	26.65	6.569	0.879
0:34:22	9.889	2.466	24.94	7.423	0.994
0:32:20	11.817	2.642	22.36	9.175	1.228
0:33:10	10.073	1.893	18.79	8.180	1.095
0:32:54	9.236	2.273	24.61	6.963	0.932
0:32:50	12.522	2.098	16.75	10.424	1.395

0:33:25	11.882	2.309	19.43	9.573	1.282
0:34:15	9.504	2.352	24.75	7.152	0.957

The highest value of recuperation energy achieved by the E-bus in the direction "A" is 2.693 kWh (28.06.2018, period from 9:12:35 to 9:40:13), the lowest value is 1.780 kWh (25.06.2018, period from 8:49:04 to 9:19:32), while the average value for all shown measurements of the realized recovery energy returned to the supercapacitor is 2.264 kWh. Analyse the ratio of realized energy recovery and the total electricity consumed by coefficients supercapacitor recovery λ_{uc_A} it can be concluded that its maximum value is 28.55%, a minimum of 16.75% and the average value realized in the direction "A" 23.20%. Graphic of measured values of supercapacitor voltage, supercapacitor charging/discharging current and SOC when the maximum recovery energy of 2.693 kWh was achieved, on the E-bus v.n. 2104 (28.06.2018, from 9:12:35 to 9:40:13), is shown in Figure 4.

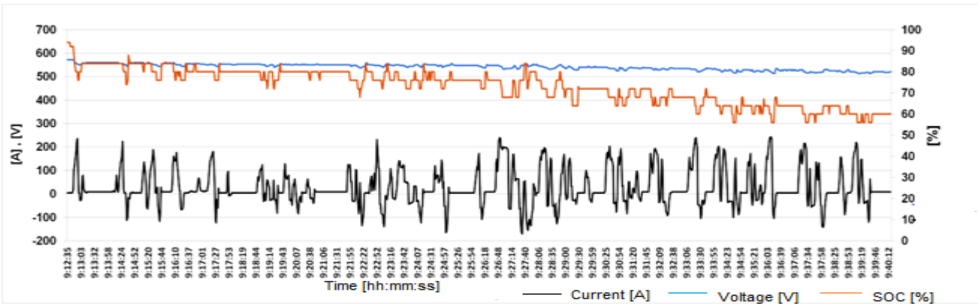

Figure 4 Values the voltage, current and SOC of supercapacitors in the period 9:12:35 to 9:40:13, direction "A", 28.06.2018

At the time of braking the E-bus, the maximum recovery current was 171.1 A at 9:27:29, at an E-bus speed of 46.9 km/h. Driving cycles that E-bus v.n. 2104 is achieved in the period from 9:12:35 to 9:40:13, is shown in Figure 5.

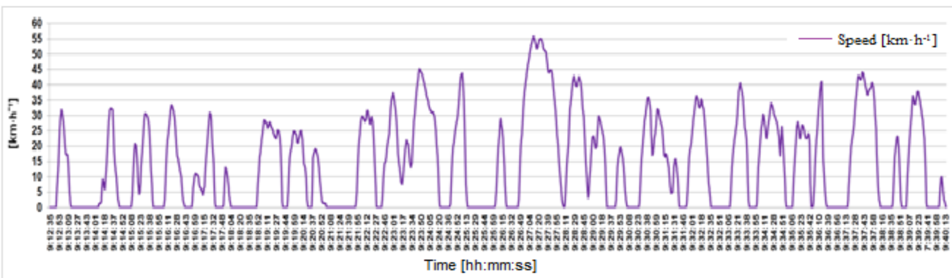

Figure 5 Values the speed of E-bus in the period 9:12:35 to 9:40:13, direction ''A'', 28.06.2018

From Figure 5, the driving time in the direction of "A" in the specified time period was 27 minutes and 40 seconds (00:27:40), which indicates the optimal traffic conditions, without traffic jams and delays, which was a prerequisite that E-bus reaches several times over 40 km/h, on Branko's bridge maximum speed was 55.2 km/h, which gave the E-bus great kinetic energy in the braking phase and the ability to generate a recovery current from 150 A to 171.1 A. For direction "B" (Belvil-Vuk's monument), the results of the energy consumed from the supercapacitor $E_{p_{ucB}}$, energy recovery $E_{r_{ucB}}$ which is returned to the supercapacitor, the recovery coefficient λ_{uc_B}, is shown in Table 2. In the direction "B" the highest value of recuperation energy generated by the E-bus is 2.510 kWh (28.06.2018, in the period from 6:47:21 to 7:18:46), the lowest value is 1.311 kWh (09.10.2019, period from 5:56:01 to 6:30:16), while the average value of the displayed results of the recovered energy returned to the supercapacitor is 1.863 kWh. The ratio of the recovered energy and the total electricity consumed by the supercapacitor is expressed in terms of the λ_{uc_B} is the maximum 19.57%, minimal 9.73% and the average value λ_{uc_B}, which is realized in the direction "B" is 14.06%.

Table 2 *Results of realized recovery energy and consumed energy in the supercapacitor, on line EKO 1, direction "B" (Belvile-Vuk's monument)*

Date [d-m-y]	E-bus	T_{spo} [°C]	Departure time [hh:mm.ss]	Arrival time [hh:mm.ss]
25-06-18	2104	13	6:22:10	6:56:59
25-06-18	2104	14	8:01:30	8:36:03
25-06-18	2104	17	9:35:30	10:09:42
25-06-18	2104	23	15:52:02	16:31:57
28-06-18	2104	16	6:47:21	7:18:40
28-06-18	2104	19	9:58:44	10:29:00
28-06-18	2104	26	16:18:40	16:59:01
27-09-18	2105	14	11:09:59	11:43:06
27-09-18	2105	16	12:44:19	13:17:55
27-09-18	2105	17	14:18:07	14:54:39
27-09-18	2105	18	15:51:33	16:28:50
08-10-19	2103	16	16:56:59	17:44:19
09-10-19	2103	8	5:56:01	6:30:16
09-10-19	2103	15	9:12:26	9:55:11
09-10-19	2103	25	13:53:21	14:32:16
09-10-19	2103	24	17:00:11	17:46:15

Table 2 *Results of realized recovery energy and consumed energy in the supercapacitor, on line EKO 1, direction "B" (Belvile-Vuk's monument)(continued)*

Driving time [hh:mm.ss]	$E_{p_{uc_A}}$ [kWh]	$E_{r_{uc_A}}$ [kWh]	λ_{uc_A} [%]	ΔE_{uc_A} [kWh]	$E_{ebus_{L_A}}$ [kWh/km]
0:34:49	11.828	1.702	14.39	10.126	10.126
0:34:33	12.372	1.844	14.90	10.528	10.528
0:34:12	10.974	1.371	12.49	9.603	9.603
0:39:55	14.434	1.866	12.93	12.568	12.568
0:31:19	13.439	2.510	18.68	10.929	10.929
0:30:16	12.806	2.506	19.57	10.300	10.300
0:40:21	17.415	2.480	14.24	14.935	14.935
0:33:07	12.736	2.333	18.32	10.403	10.403
0:33:36	11.264	1.732	15.38	9.532	9.532
0:36:32	12.497	1.931	15.45	10.566	10.566
0:37:17	12.677	1.909	15.06	10.768	10.768
0:47:20	13.877	1.567	11.29	12.310	12.310
0:34:15	13.477	1.311	9.73	12.166	12.166
0:42:45	13.764	1.355	9.84	12.409	12.409
0:38:55	14.649	1.809	12.35	12.840	12.840
0:46:04	15.225	1.576	10.35	13.649	13.649
0:34:49	11.828	1.702	14.39	10.126	10.126

An even greater degree of recuperation in direction "A", was achieved in the ''Study of the impact of driving style on the energy efficiency of the E-bus'' [4], when the driver strictly applied the manufacturer's recommendations and the recommendations from the polygon test [4]. In a real drive conducted on 22.01.2020, in the period of intermediate load and optimal traffic conditions, the maximum recuperation coefficient was achieved of $\lambda_{uc_A} = 29.18$%, ($E_{p_{uc_A}} = 9.559$ kWh, $E_{r_{uc_A}} = 2.789$ kWh). The ride lasted 27.5 minutes. In order to better understand the values of λ_{uc}, we will list the results of measurements performed on the city line No.29 (Dorćol-Medaković III). In the test conducted with the E-bus (Higer KLQ6125GEV3) on the line No.29 (Dorćol-Medaković III) the degree of recovery expressed through the ratio of the regenerated and total electricity consumed achieved in the direction "B" is 33.77% [5]. If compare the obtained values of the recuperation coefficient on line EKO 1 and line No.29, where the direction "B" is declining for most of the route (about 70% of the line) and where is the maximum a drop of the road section 5.5%, E-bus has a significantly higher recovery rate achieved.

3. CONCLUSIONS

Based on the presented measurement methodology the acquisition of current values of current and voltage via BMS control unit E-bus (Higer KLQ6125GEV3) in real operating conditions on the line EKO 1, it was concluded that the highest degree of recovery is expressed through the ratio of recovered energy to supercapacitor and total consumption electricity from the supercapacitor, achieved in the direction "A" is 28.55%, while the maximum value in the direction "B" is 19.57%.

From the point of view of the impact on the achieved degree of recuperation and electricity consumption, it is important to point out that in the direction "A", from stations Zeleni venac-Block 21, has a constant drop of about 2.1% on a section of about 1.9 km. In the direction "A", the number of transported passengers is smaller, on the section in decline there are fewer resistance forces that occur in the phase of the movement which has an impact on less consumed electricity in the direction of "A".

In the mentioned section over Branko's bridge, the E-bus achieves the maximum speed of movement so that the maximum utilization of the kinetic energy of the E-bus during regenerative braking is possible, which is reflected in the amount of regenerated electricity returned to the supercapacitor. In the direction "B", the load of the E-bus is higher on the mentioned section, as well as the resistance forces of the movement, which affects the higher required electricity for movement. The ascending route and the lower maximum speed that is reached on the section over Branko's bridge affect the lower possibility of electricity recovery compared to the movement in the direction "A". It is obvious that the size of the recovery coefficient under the assumption that the regenerative braking system is used correctly is mostly influenced by the terrain configuration i.e. the presence of a road sections with decline.

ACKNOWLEDGMENTS

This paper is part of the research in the doctoral dissertation "Energy and environmental performance of electric buses in the passenger transport system", which is in the process of making, by the author Slobodan Mišanović. The author thanks everyone who helped in the realization of the research. Also, the paper is the result of the researches within the project TR 35041 that is supported by the Ministry of Education, Science and Technological Development of the Republic of Serbia.

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MOBILITY & VEHICLE MECHANICS

DOI: 10.24874/mvm.2021.47.04.05
UDC: 340.137

VEHICLE LEGISLATION – SERBIA VS. EUROPE

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Received in July 2020 *Revised in August 2020* *Accepted in September 2020*

RESEARCH ARTICLE

ABSTRACT: The current state of vehicle technology development has been characterized by the production of a very wide range of different types and categories of vehicles. Modern vehicles are characterized by a great complexity of fitted parts and mechanisms. These facts inevitably lead to the intensive development of legislation that cover the entire field of the automotive industry, as well as its harmonization at the international level. From the very beginning of harmonization, Yugoslavia has played a very active role in the development and implementation of the Regulations adopted within the United Nations, the Economic Commission for Europe. As the legal successor, Serbia continued on that path, but due to the situation in the previous 30 years, the activities within the harmonization of regulations have been significantly slowed down, primarily with the European legislation. The paper presents the current state of harmonization of regulations in Serbia with European legislation, as well as certain inconsistencies that occurred during the application of national regulations and performed comparative analysis. Also, an overview of the plan for harmonization of legislation has been given, and some examples of noncompliance are pointed out, which should be overcome with the proposed harmonization plan.

KEY WORDS: UN Regulations, EU Directives, Harmonization

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ZAKONSKA REGULATIVA O VOZILIMA - SRBIJA VS. EVROPA

REZIME: Trenutno stanje razvoja tehnologije vozila karakteriše proizvodnja veoma širokog spektra različitih vrsta i kategorija vozila. Savremena vozila odlikuje velika složenost ugrađenih delova i mehanizama. Ove činjenice neizbežno dovode do intenzivnog razvoja zakonodavstva koje pokriva celo područje automobilske industrije, kao i do njegovog usklađivanja na međunarodnom nivou. Od samog početka usklađivanja, Jugoslavija je imala veoma aktivnu ulogu u razvoju i primeni uredbi usvojenih u okviru Ujedinjenih nacija, Evropske ekonomske komisije. Srbija je kao pravni naslednik nastavila tim putem, ali su zbog stanja u prethodnih 30 godina aktivnosti u okviru usklađivanja propisa znatno usporene, pre svega sa evropskim zakonodavstvom. U radu je prikazano trenutno stanje usklađenosti propisa u Srbiji sa evropskim zakonodavstvom, kao i određene nedoslednosti do kojih je došlo tokom primene nacionalnih propisa i izvršene uporedne analize. Takođe, dat je pregled plana usklađivanja zakonodavstva i ukazano je na neke primere neusklađenosti koje bi trebalo prevazići predloženim planom usklađivanja.

KLJUČNE REČI: propisi UN, directive EU, usklađivanje

VEHICLE LEGISLATION – SERBIA VS. EUROPE

Saša Mitić, Ivan Blagojević, Dragan Stamenković

INTRODUCTION

The automotive industry is one of the leading branches of industry in the world. The development of technology, the accessibility of new products to an expanding population, as well as the increase in living standards and population needs, lead to a much wider offer of automotive products, both by categories and types of vehicles and their equipment. Accordingly, the automotive industry is a synthesis of traditional and modern technologies, which leads to the engagement of top experts in very different fields (mechanical engineering, electronics, electrical engineering, technology, design, aerodynamics, ecology, economics, etc.). With the development of the automotive industry throughout history and the increasing use of vehicles as an integral part of the daily functioning of all mankind, the need for the development of national and international regulations have emerged. This development is inevitably more and more intensive, so the need for harmonization of regulations have become extremely important. Demands for more and more frequent amendments to the existing, but also the development of completely new regulations, required a very demanding organization of national and international organizations that have been established and are in charge of their implementation. The feasibility of the regulations implementation, required the creation of mechanisms that will enable efficient work on regulations, as well as their rapid implementation. For that cause, each country delegated at the national level the bodies in charge of enacting, implementing and harmonizing of regulations, but at the same time they worked on the establishment of international organizations, which were supposed to be in charge of regulations at the international level. Meanwhile, international organizations have been established within the United Nations, but also at the level of the European Union.

1. HISTORY OF VEHICLE LEGISLATION

1.1 European Union

Starting in 1970, the European Union began to develop a system of laws and regulations (EEC Directives), which also applied to the automotive industry and technical regulations in it. The first official Directive adopted was 70/156/EEC (dated 6 February 1970), and concerned the type-approval of motor vehicles and their trailers. It was later the basis for all other Directives. Until 1993, the Directives were marked with an extension EEC (European Economic Community), from 1993 to 2009 with an extension EC (European Community), and from 2010 with an extension EU (European Union) [1]. The adoption of these regulations was aimed at unifying the national regulations of the Member states and had to go through the procedure of acceptance and harmonization in each Member state separately.

1.2 Serbia

Shortly after the establishment of the 1958 Agreement at the United Nations Economic Commission for Europe (UNECE), Yugoslavia, as the tenth country in a row, signed the Agreement in 1962, guided primarily by the following goals:

- increasing of vehicle active and passive safety
- environmental protection

- creating the conditions for undisturbed circulation of products in international trade, e.g. for unobstructed exports of domestic products of the automotive industry and related comapnies
- prevention of imports of non-homologated (we can say unsafe) products, as well as the protection of the domestic market from low-quality imported and domestic products
- active involvement of domestic scientific, R&D and production capacities in modern trends of technological and normative requirements, etc.

This shows a clear intention and vision to direct the domestic industry and society towards the immediate inclusion of all activities in all current trends in the development of the European and World automotive industry. With the breakdown of the former Yugoslavia during the 1990s, the Republic of Serbia legally accepted the role of the legal successor of Yugoslavia. This was a logical move, because Serbia retained all the institutional positions of the former state, so it did not have to spend time on accession, negotiations and checking the fulfillment of conditions for membership in various international organizations. Thus, as the legal successor of Yugoslavia, the ordinal number of the signature of the 1958 Agreement was retained, so all homologation Approvals issued by the Competent Authority of the Republic of Serbia are marked "E10". However, the legal heritage brought with it not only privileges and advantages, but also a burden and an obligation to deal with. All the new states created by the breakdown of the former Yugoslavia, except Republic of Serbia, were completely relieved of their obligations to international institutions, so from the very beginning they were in a position for planning the strategy for enactment of regulations. Therefore, it was easier for them to harmonize with the structure and policy of the regulation in all areas, and thus in the field of automotive industry and traffic safety. On the other hand, the hard breakdown of Yugoslavia, along with war conflicts, sanctions, but also the already mentioned legal legacy, posed a great burden for Serbia due to the impossibility of regular monitoring of the current state of regulation, so these "lost" twenty years have left their mark on the harmonization and implementation of international regulations. Just with the signing of the Agreement with the European Union on the beginning of accession negotiations for Serbia's membership in the EU, the analysis and harmonization plan of domestic legislation with the European one has began. This accession agreement, among other things, established negotiating groups for the harmonization of legislation, with clearly defined deadlines for full harmonization of regulations.

2. THE STRUCTURE OF APPLIED REGULATIONS

2.1 UN Regulations

The 1958 Agreement [7] is one of the UNECE Agreements that aims to establish uniform standards for vehicles and their components, in terms of safety requirements, environmental protection, as well as in terms of energy efficiency. The Agreement seeks to promote the harmonization of UN Regulations and the mutual recognition of approvals between the Contracting parties to the Agreement. It was adopted on March 20th, 1958 in Geneva, upon the proposal of the Federal Republic of Germany, and entered into force on June 20th, 1959, after it was signed by several European countries. Its primary, original name is "Agreement Concerning the Adoption of Uniform Conditions of Approval and Reciprocal Recognition of Approval for Motor Vehicle Equipment and Parts". In its original form, the Agreement allowed only UNECE Member states to participate. The second revision of the Agreement was made in 1995, when its name was partially changed to the current one - "Agreement

Concerning the Adoption of Uniform Technical Prescriptions for Wheeled Vehicles, Equipment and Parts Which Can Be Fitted and/or Be Used on Wheeled Vehicles and the Conditions for Reciprocal Recognition of Approvals Granted on the Basis of These Prescriptions". The second revision entered into force on October 16th, 1995. The aim of this second revision, among other things, was to promote the inclusion of non-European countries in a united approval system and to raise the Agreement to a global level. Significant success has been noted in this area. However, the Agreement still contains certain provisions that prevent certain states from becoming its Contracting Parties, due to their national legislation. So far, 57 member states of the United Nations (10 of which are non-European countries) have joined this Agreement, as well as one regional integration organization (European Union). The newest UN member state that have joined the Agreemnt is Pakistan, which acceded to the Agreement in 2020. That shows that the Agreement continues to expand and fulfills its mission. Of all the European member states of the UNECE, only 7 of them did not sign the 1958 Agreement. These are practically only the smallest European countries, which have no influence in the vehicle industry (Andorra, Iceland, Liechtenstein, Monaco and Vatican), or their geopolitical position dictates their current position under the Agreement (Israel, Moldova). A much more important fact for the 1958 Agreement and its expansion is that both UNECE member states from the North American continent (Canada, USA) did not sign the Agreement. On the other hand, Kazakhstan acceded to the Agreement in 2011, as the first Central Asian country. The overall importance of the Agreement itself can only be seen when we take into account the fact that, in addition to almost all European countries, among the non-European countries that joined the Agreement are some of the most important in the automotive industry (Japan, Republic of Korea, Thailand, Malaysia, Australia, South Africa), as well as the European Union itself, for sure globally the most influential international regional organization.

2.2 EU Directives

In most cases, the EEC/EC/EU Directives are, in terms of technical requirements, completely identical to the UN Regulations. With a very small number of Directives and relevant Regulations, there are significant differences in terms of technical requirements. The identity of the technical requirements of the Directives and the UN Regulations has the consequence that currently a significant number of UN Regulations are integrated into the EU Approval system. An additional explanation is needed due to the introduction of a new term in the titles of legislation – the Regulation. It must be emphasized that this is not about the UN Regulations, but about the concept by which the European Union wanted to make a difference in the obligation and the way of implementing its legislation. Namely, regulations are the most direct form in EU legislation - as soon as they are adopted, they become mandatory for application in all EU Member states, in parallel with national laws. The Governments of the Member states do not need to take any additional measures to enforce this type of document. On the other hand, Directives are forwarded to national institutions, which have to take corresponding measures to incorporate them into their legislation. The last Directive relating to motor vehicles was adopted in early 2010, from which it can be concluded that the EU has practically abandoned this form of regulatory acts in the automotive sector, which certainly leads to an increasing level of harmonization of regulations in EU Member states. EU Decisions are documents of the lowest binding rank for Member states, and have to be applied only in specific cases. Each EU Regulation must be adopted by the Council of the European Union and the European Parliament, as well as by the European Commission itself. This system of legal regulations is applied in all sectors, not only in the automotive. The first Regulations in the field of vehicle Approval were adopted in 2007.

2.3 Serbian legislation

2.3.1 The Law on Road Traffic Safety

The basic document that deals with all issues related to the wide field of traffic safety, including vehicles, is the Law on Road Traffic Safety [4], entered into force in 2009. This law regulates traffic rules, behaviour of traffic participants on the road, traffic restrictions, traffic signals, signs and orders that must be followed by traffic participants, conditions that must be met by drivers, training of candidates for drivers, driving exams, the right to drive vehicles, issue of driving licenses, issue of vehicles stickers for people with disabilities, conditions that must be met by vehicles, technical inspections, testing and registration of vehicles, special measures and authorizations applied in road traffic, as well as other issues that relate to road safety. An indisputable fact is that the enactment of this law was necessary, especially taking into account the time period that has elapsed since the enactment of the legal acts that preceded to this one. On the day this Law enters into force, the Law on Basics of Road Traffic Safety and the previous Law on Road Traffic Safety ceases to be valid, except with regard to certain articles, which shall apply until the adoption of the relevant bylaws. The Law on Road Traffic Safety stipulates that the Government, at the proposal of the Ministry in charge of traffic affairs, establishes the Road Traffic Safety Agency, as a public agency responsible for carrying out all activities related to the implementation of regulations on vehicle homologation and testing, as well as traffic safety.

2.3.2 The Regulation on Motor Vehicles and Their Trailers Classification and Technical Conditions for Vehicles in Road Traffic

This Regulation [6] prescribes the classification of motor vehicles and their trailers, conditions that must be met by vehicles in traffic on the road in terms of dimensions, technical conditions and devices, assemblies and equipment and technical standards, the way, time of possession and use of winter equipment on vehicles in road traffic. as well as conditions regarding the use and technical characteristics of the tourist trains. Article 342 of the Law on Road Traffic Safety defines that this Regulation is adopted by the Minister in charge of traffic affairs within six months from the day the Law enters into force. This work was slightly delayed, so that this Regulation entered into force on September 20th, 2010. However, it quickly became clear that there were a number of ambiguities and inconsistencies in the Regulation, so after two amendments to the original document, a new version of Regulation was published in the Official Gazette of the Republic of Serbia in 2012. This new verion so far had eight amendments.

2.3.3 Regulation on Vehicle Testing

This Regulation [3] prescribes the procedures and way of testing of motor vehicles and their trailers, issuing certificates and keeping records on performed tests of motor vehicles and trailers. Pursuant to Article 249, paragraph 5 of the Law on Road Traffic Safety, this Regulation was adopted by the Minister of Infrastructure and Energy, because according to the previous organization of the Government of the Republic of Serbia, he was in charge of traffic affairs.

2.3.4 Regulation on Homologation (draft)

Having in mind that the area of homologation and conformity control is not completely legally regulated, the Traffic Safety Agency, in cooperation with the Faculty of Mechanical Engineering, University of Belgrade, made a proposal for the Regulation on homologation [2], which is expected to be adopted and applied soon. This Regulation prescribes:

- more detailed conditions on the procedure and way of homologation or approval of individually or serially produced vehicles (complete, completed, modified and incomplete), ie devices, assemblies and equipment on vehicles
- more detailed conditions on the procedure and way of controlling the conformity of newly manufactured vehicles, ie devices, assemblies and equipment on vehicles
- more detailed conditions on the procedure and way of control of conformity of production of vehicles, ie devices, assemblies and equipment on vehicles.

The proposal of the Regulation stipulates that vehicle Approval tests may be carried out in one phase in the case of incomplete and complete vehicles, or in several phases as multi-stage approval in the case of completed or modified vehicles. An individual vehicle approval is carried out for an individually completed, modified or individually manufactured vehicle. The name of the manufacturer, as well as the make, type, variant and version of the individually completed or modified vehicle does not change in relation to the name of the manufacturer, make, type, variant and version of the incomplete or base vehicle. The manufacturer of an individually manufactured vehicle defines the make, type and commercial mark, as well as the VIN mark and the manufacturer's plate. The appendix to the draft Regulation defines the procedures for each vehicle category. According to the proposal of the Regulation, compliance with the conformity control checks the fulfillment of technical conditions in accordance with the regulations in the field of road traffic safety. Conformity control of imported vehicles, ie vehicles manufactured, completed or modified in the Republic of Serbia is carried out in relation to the type of serially or individually newly produced complete, completed or modified vehicle, for the purpose of placing on the market or placing on the road. Conformity control of devices, assemblies and equipment on imported vehicles, if specifically prescribed, shall be carried out in relation to the type of appropriate device, assembly and equipment of vehicles, for the purpose of placing on the market. The manufacturer is obliged to ensure the continuous application of procedures that ensure the conformity of production. The tasks of controlling the conformity of production include the review of the submitted documentation, the preparation of the homologation Test report and the issuance of a Compliance statement.

2.3.5 Tha Law on Transport of Dangerous Goods

Vehicles intended for the transport of dangerous goods in the Republic of Serbia are regulated by the Law on Transport of Dangerous Goods [5], The European Agreement concerning the International Carriage of Dangerous Goods by Road (ADR) [8] which has been ratified by the Republic of Serbia and which is referred to in the mentioned Law, as well as the Regulation on the way and procedure of issuing ADR vehicle approval certificates. According to the Law on Transport of Dangerous Goods (Article 42), the compliance of vehicles with the requirements of Chapters 9.2 - 9.8 of the ADR have been confirmed by issuing an ADR certificate of approval for a vehicle for transport of dangerous goods (hereinafter: ADR certificate of approval for a vehicle). technical characteristics of the vehicle and prescribed documentation. In addition to the requirements of Chapters 9.2 - 9.8 of the ADR, a vehicle that is individually or serially manufactured or modified must be technically correct and comply with uniform technical conditions in accordance with the regulations on homologation, ie the conditions prescribed by the Law on Road Traffic Safety. The requirement that the vehicle must be harmonized with uniform technical conditions, as it is prescribed for all vehicles and the Law on Road Traffic Safety, opened a number of problems for vehicle owners who do not meet the mentioned requirement. These are vehicles that have already been registered in the Republic of Serbia and received the first

ADR certificate of approval for the vehicle before the entry into force of the Law on Transport of Dangerous Goods, ie the establishment of the Transport Administration dangerous cargo in 2012. These are mainly trailers - tanks of domestic production (Gosa, Utva, Vozila Gajic) for which there are no Approvals on homologation according to UN Regulation R13, towing vehicles (tractors) for which there are no Approvals on homologation according to UN Regulation R105, as well as trailers on which the brake system was repaired (eg subsequent installation of anti-lock devices - ABS), ie replacement of axle assemblies without appropriate documentation, testing and checking. Both of these UN Regulations are specifically emphasized in Part 9 of the ADR Agreement and are mandatory in the Republic of Serbia. The mentioned problem forced the lawmakers to enable a transitional period for the use of the mentioned vehicles through transitional and final provisions (Article 75), until December 31st, 2017, ie December 31st, 2018 for vehicles that were not tested after the conversion. Pursuant to Article 26 of the Law on Amendments to the Law on Transport of Dangerous Goods, the stated deadlines have been extended until December 31st, 2021. It remains to be seen whether this deadline will remain or a new shift will occur due to a known problem with the Covid19 disease. The vehicle fleet intended for the transport of dangerous goods in the Republic of Serbia, which is subject to the requirements of Part 9 of the ADR, and which numbers about 2,500 vehicles, has been significantly renewed in the last few years. This fact, as well as the write-off of older vehicles, reduced the number of legally "disputed" vehicles (it is estimated that their number ranges between 250 and 300 vehicles). The Regulation on the way and procedure of issuing ADR vehicle approval certificates (hereinafter the Regulation) prescribes in detail the way and procedure of issuing ADR vehicle approval certificates, ie documents proving compliance with requirements. An age limit of 15 is introduced for vehicles that are issued for the first time with an ADR certificate of approval for a vehicle in the Republic of Serbia. The Regulation structures vehicles (newly manufactured, vehicles imported as used, vehicles already registered in the Republic of Serbia, vehicles that fully or partially (due to inherited condition) meet the prescribed requirements) and requirements regarding documentation proving the necessary compliance. In that sense, the level of requirements for a new vehicle produced, both in the country and abroad, is identical and corresponds to the one valid in the countries of the European Union. The only difference relates to the application of UN Regulation R111, which refers to the lateral stability of vehicles with superstructures (in this case, tank vehicles with a test pressure of less than 4 bar) for new vehicles manufactured in the Republic of Serbia. The mentioned approval is not required for the vehicles according to the mentioned Regulation, but the proof of fulfillment of the technical requirements contained therein, which must be confirmed by the Notified body. The derogation introduced by the Regulation was due to a very small number of new types and units of domestically produced tank vehicles, as well as the lack of an authorized Technical Service for UN Regulation R111. Also, the Regulation defines that the notification of homologation according to UN Regulation R105 is mandatory for all newly manufactured vehicles applying for the ADR certificate of approval for a vehicle in the Republic of Serbia, except for vehicles of category N1 which are classified as EX/II vehicles in accordance with ADR. Manufacturers of vehicles of the specified category (N1) do not perform homologation tests according to the specified Regulation at all.

3. INCONSISTENCIES OF EU AND SERBIAN LEGISLATION

3.1 Causes and reasons for incompliances

An additional problem of the current legislation in the Republic of Serbia is the way of enacting the currently valid regulations. As a basis for the adoption of the Law on Road

Traffic Safety and all other regulations and documents, the existing regulations were used, which were already outdated in terms of structure and content, so it turned out that the new regulations, despite great engagement, contained too many inconsistencies with the accepted international regulations, but also with regulations valid in Europe. The problem is reflected in the import of new and used vehicles from the area of Europe, where during the conformity control of vehicles with domestic regulations, incompliances are established, ie collision of certain articles of domestic regulation with the relevant UN Regulations or EU Directives, or even a complete lack of regulation (example: the status of old-timers in the Republic of Serbia). This was the reason for a large number of amendments to the existing domestic regulations (each of the regulations was amended at least once a year). These amendments mainly referred to the corrections of incompliances, which were successively revealed by additional analysis of regulations or through solving direct problems in practice. With the existing structure of domestic regulations, the problem of harmonization with international regulations remains permanently open. This is supported by the previously mentioned fact that changes in European regulations are becoming more intensive, and even monitoring these changes is a problem, and changes and additions based on that are practically impossible.

3.2 The possibility of applying the European concept of regulations

Having all the above in mind, with the signing of accession negotiations with the EU, a detailed analysis of all regulations in the Republic of Serbia (including the part concerning traffic safety) has begun to be considered. According to that, an Action Plan has been established for the activities carried out by the Republic of Serbia in the process of European integration within the plan for full harmonization of regulations in the field of motor vehicles, offroad mobile machinery, motorcycles and agricultural and forestry wheeled tractors. This plan defines the following segments:

- a list of EU Regulations that need to be transposed into the legislative system of the Republic of Serbia has been defined
- the Competent body for the harmonization of regulations have been determined, as well as an organizational unit within the Competent body and contact persons
- for each EU Regulation, the legal basis for the adoption of regulations implementing harmonization is given, as well as the regulation in the Republic of Serbia
- planned deadlines for harmonization of regulations are defined
- As a result of harmonization, the deadlines for the adoption of harmonization are given, as well as draft regulations, compliance tables and the Opinion of the European Commission.

Road Traffic Safety Agency has been defined as the Competent body for the implementation of the Action Plan, with the names of EU Regulations and planned deadlines for harmonization. The originally scheduled deadlines (end of 2017 and end of 2018, depending on the regulations) have been changed and moved several times for various reasons. The current situation with the deadlines for harmonization with EU regulations is unknown.

4. CONCLUSIONS

The Republic of Serbia's strong commitment to be an equal member of the European Union unequivocally indicates that the harmonization of all legislation is an obligation that needs to be implemented before final accession. Having in mind the extension of the harmonization deadlines envisaged by the Action Plan, it becomes quite clear that in order to achieve the harmonization of the legislation of Serbia with the EU, it is necessary to significantly involve the competent state institutions. In the case of the part of regulations concerning traffic safety and homologation of vehicles, equipment and parts, the authority is fully assigned to the Road Traffic Safety Agency, so it is rightly expected to implement the complete procedure envisaged by the Action Plan both in organizational and personnel terms. Therefore, it is necessary to significantly engage scientific and professional institutions and staff, who with their knowledge and experience can greatly contribute to the acceleration of the entire process. All necessary analysis of the current situation, as well as optimal solutions for harmonization of regulations that take into account all the specifics of a particular matter can be significantly accelerated with the contribution of the scientific and professional public. However, the area of traffic safety and vehicle homologation, as part of the entire legislation of the Republic of Serbia, has too many specifics for the entire harmonization process to be implemented in a short period of time. Therefore, for the next period, it is crucial to define, as far as possible, realistic deadlines for the implementation of the Action Plan. It is estimated that a lot of time and engagement is needed in order to reach the final harmonization of regulations and implementation in the Republic of Serbia.

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