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INFLUENCE OF VANES SHAPE ON THE HIGH FREQUENCY NOISE OF VENTILATED DISC BRAKES IN HEAVY VEHICLES

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ABSTRACT: Brake is a device for slowing or stopping the vehicle. The sound that occurs in the process of braking is very irritating for the driver. Brake systems of road vehicles as important factor in overall vehicle noise have attracted great attention. All global brake system manufactures are focused to the quieter brakes. This paper presents an analysis of differentially variants of brake disc, and how the structure itself influencing the occurrence of noise. The weight of analyzed discs is approximately equal to each other. The analysis was performed in the software package ANSYS, while the model was created in CATIA.

KEY WORDS: noise, brakes, manufactures, structure, modal analysis

UTICAJ OBLIKA REBARA NA VISOKOFREKVETNU BUKU VENTILIRAJUĆIH DISK KOČNICA TERETNIH VOZILA

REZIME: Kočnica je uređaj za usporavanje ili zaustavljanje vozila. Zvuk koji se javlja u procesu kočenja je jako iritirajući za vozača. Veliku pažnju kod drumskih vozila upravo su privukli kočni sistemi kao važni faktor u ukupnoj buci vozila. Svi svetski proizvođači kočnica su se usmerili ka tišim kočnicama. U radu je prikazana analiza za različitie varijante disk kočnica, odnosno kako sama konstrukcija utiče na pojavu buke. Analizirane varijante diskova su približno istih masa. Analiza je izvršena u softverskom paketu ANSYS, dok je model izrađen u CATIA.

KLJUČNE REČI: buka, kočnice, proizvođači, konstrukcija, modalna analiza.

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INFLUENCE OF VANES SHAPE ON THE HIGH FREQUENCY NOISE OF VENTILATED DISC BRAKES IN HEAVY VEHICLES

Nadica Stojanović [1], Jasna Glišović [2], Jovanka Lukić [3], Ivan Grujić [4]

1. INTRODUCTION

Brake is a device for slowing or stopping the rotation of a wheel while maintaining stability of vehicle. The auxiliary brakes have important task to keep the vehicle stationary. There are two basic design solutions of friction brakes as the executive mechanisms of road vehicles braking systems: the disc and drum brakes. However, today the largest application in both passenger and commercial vehicles, have the disc brakes. Paper title points out that the paper will be focused on the disc brakes of heavy-duty commercial vehicles. Braking in this case is accomplished by the friction that occurs in the contact of disc and the pads.

One of the main characteristics of a modern urban society is the growing presence of sounds that cause discomfort. A large number of sounds one experiences subjectively. The sound can be pleasant and unpleasant. Pleasant sounds are those like the twitter of birds, or favourite songs, while the unpleasant sounds are very irritating. Unpleasant sounds can be like music that an individual does not like or sounds typical for the industrial areas. These sounds are called noise [1]. Noise is one of the stimulus from the environment which acts on the man and affecting his health, working ability and comfort [2].

Brake noise and judder of road vehicles are of great importance both for manufacturers and for the customers [3]. The noise level in any area is in direct correlation with the quality of life there, as well as the environment pollution [4]. Also, the noise level of the brake system is directly reflected on road safety. Noise level directly affects alertness of drivers. A large number of research and experience have raised the level of understanding of the occurrence of brake noise. By applying the experience of others, still in the design phase, susceptibility to noise and vibration is significantly reduced.

In the process of finding solutions to reduce the noise of the brake system, Nouby and Srinivasan [5] have carried out a few analyses. Analyses included some of the factors that contribute to the noise generation. The conclusions reached by the authors of this paper are:

- The higher coefficient of friction increases the possibility of noise,
- The brake noise can be reduced by decreasing the stiffness of the back plates of the pads, and

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- Increasing the size of the chamfer provided significant noise reduction.

Reduction of brake noise is possible to achieve by the design modifications of a disc [6]. Several structural changes were made to the disc, and the analysis was performed for each change using CAE. The modifications that were made to disc: the change in the number of blades, the thickness of the neck, as well as height, holes on the disc etc. Despite numerous modifications made to the disc and any change was tested, it was shown that noise cannot be eliminated. The noise that occurs in the brake system depends not only on the design of the disc.

Mat Lazim and others [7] showed that the wear of brake pads surface affect the squeal of brakes. Also, this paper shows that it is not the same level of noise if it is a new brake pad or brake pad that is already in operation. Based on the research results, it was concluded that for the development of quieter brake system, it is essential to understand the topography of brake pad surface.

The aim of this paper is to examine how the shape of the brake disc ribs affects the brake noise, which occurs in the process of braking.

2. CAD MODEL OF BRAKE DISC

A compressed air disc brake system is a type of friction brake for vehicles in which compressed air pressing on a piston is used to apply the pressure to the brake pad needed to stop the vehicle. Air brakes are used in large heavy vehicles, particularly those having multiple trailers which must be linked into the brake system, such as trucks, buses, trailers, and semi-trailers. Air disc brake (ADB) is the execution unit of automobile brake, which plays a vital role in traffic safety. The first air brakes were primarily developed for use in railway vehicles. The main reason for the application was to improve their braking responsiveness and safety and avoid the all too frequent train crashes. Westinghouse made numerous alterations to improve his air pressured brake invention, which led to various forms of the automatic brake. In the early 20th century, after its advantages were proven in railway use, it was adopted by manufacturers of trucks and heavy road vehicles [8]. Air disc brake assembly modelled in CATIA software package is shown in Figure 1.

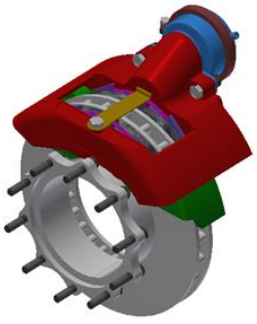


Figure 1. *Air disc brake in heavy duty commercial vehicles*

The braking system assembly consists of a large number of parts (Figure 1). However, in the analysis that is performed in the paper, only brake disc and pads are observed. Friction pair consists of disc and brake pads is modelled in the software package CATIA and as such will be imported into the software for further analysis. The design of the

disc varies somewhat. Some are simply solid, but others are hollowed out with ribs or vanes joining together the disc's two contact surfaces. The weight and power of the vehicle determines the need for ventilated discs. The ventilated disc design helps to dissipate the generated heat under extreme braking conditions and is commonly used on the more-heavily-loaded front discs. The outer diameter of the analysed disc is 430 mm [9]. The analysis is performed for the completely new disc, whose height is 131 mm and thickness is 45 mm. Four variants of the ribs of the brake disc are shown in Figure 2.

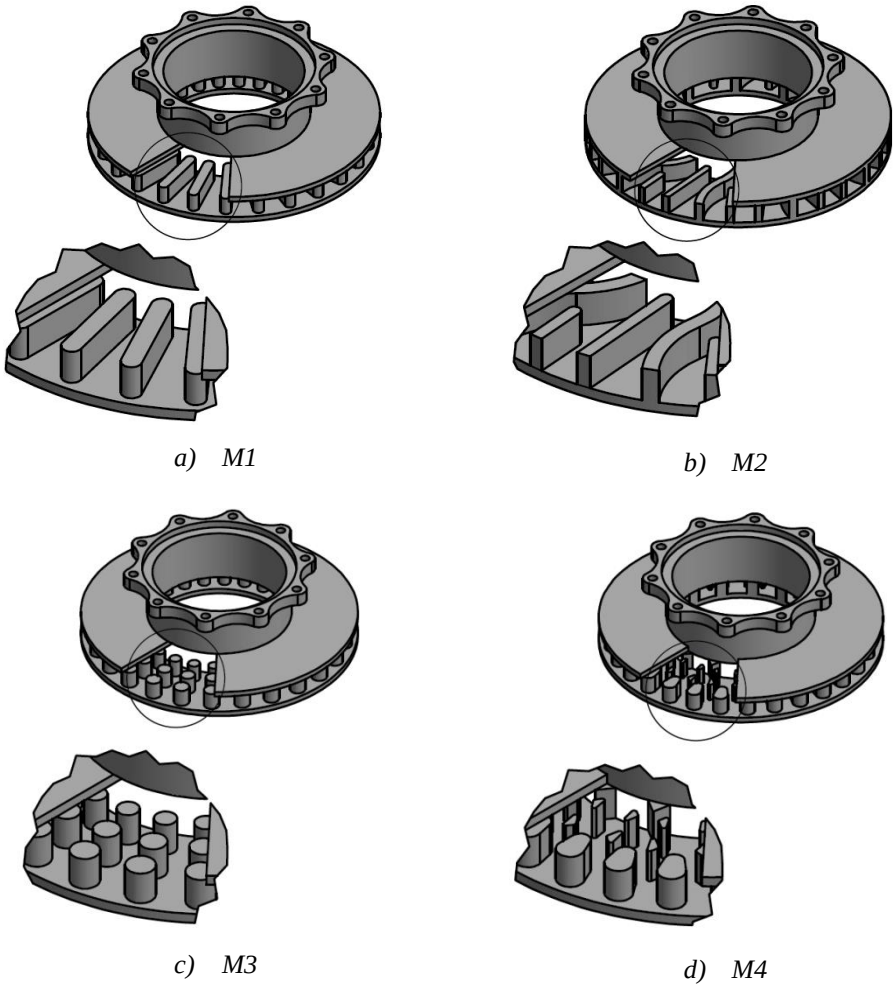


Figure 2. *Ventilated brake disc with various variants of the ribs*

In most vehicles these brake discs are made of cast iron, which has good antiwear properties and it is cheap as well. The material used for the disc is cast iron, while the friction material is used for the brake pads. Material properties are shown in Table 1, while Table 2 shows the mass variations of each disc. It is obvious that the mass of the discs is approximately equal.

Table 1. *Material properties of the brake disc and brake pads [10]*

	Density (kgm^{-3})	Young's modulus (GPa)	Poison ratio (-)
Disc	7250	138	0.28
Pads	1400	1	0.25

Table 2. *Mass of discs with different variants of the ribs*

	M1	M2	M3	M4
Weight [kg]	24.332	24.267	24.359	24.226

1.1 Boundary conditions

Boundary conditions are applied according to the loading for the real component of the structure. First, it is necessary to define the initial conditions. Initial conditions are defined in the module Static Structural. An environmental condition, in which the vehicle is tested, defines with the ambient temperature of 22˚C.

Brake squeal is predominantly generated at low vehicle speeds (below 30 km/h) and at low brake pressures (brake line pressure below 2 MPa). From many experimental observations, it is known that squeal usually occurs at slow rotational speeds (around 0.1-1 Hz or 6-60 rev/min) towards the end of a stop. The vehicle is moving with a speed of 20 km/h and braking until it completely stops. Based on the initial speed of the vehicle and the tire diameter, calculated angular speed is 10 rad/s.

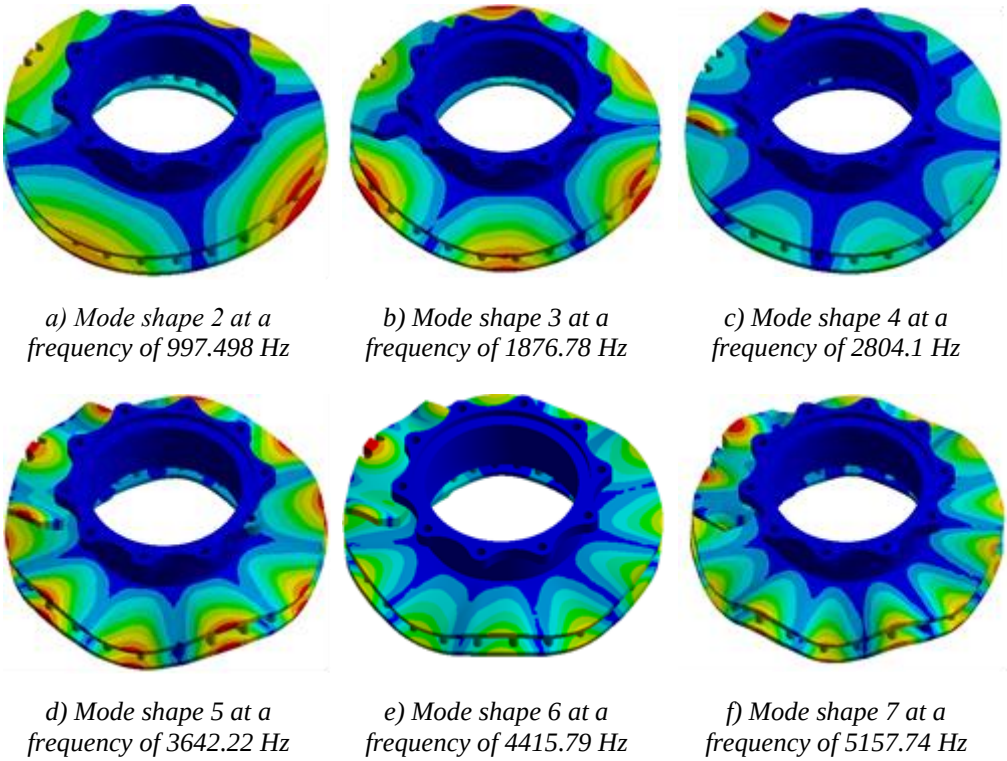
Brake squeal noise is the result of vibration created by coupling of two vibration modes of brake component such as pads, rotor, calliper, suspension links etc. In mode coupling mechanism, two modes of vibration geometrically matched (same wavelength) and close resonances can induce more energy into the system than it can dissipate. The mode coupling is often locked depending on operational conditions such as (speed, pressure and temperature) and interface characteristics such as contact stiffness, roughness, adhesive force, etc. Actually, the disc speed is an indirect simulation parameter in the sense that it affects the friction coefficient which plays a major role in the analysis.

Friction in most mechanical element is undesirable phenomenon. However, in the brake system it is very desirable. Without friction vehicle could not be stopped. Brake friction pair, namely the friction material and the rotor, is the area where the friction is realized over a wide range of operational and environmental conditions. The value of the coefficient of friction is 0.336 [11].

1.2 Modal analysis

Modal analysis has become one of the most important tools in the design and structural optimization of mechanical product. It has been used effectively in the identification of structural dynamic characteristics and has become a flourishing area of vibration research [12]. Modern constructions should be as lightweight and simple, but at the same time strong enough [13]. These requirements are the most prominent in the automotive industry. However, if you do not pay attention, it can lead to undesirable vibrations in certain vehicle operating modes.

Modal analysis is the process of determining the basic dynamic properties of the structure, such as natural frequency, damping and oscillation modes, in order to formulate the dynamic behaviour of the model. The analysis is based on the fact that the vibrations of the nonlinear dynamic system can be represented by the sum of simple harmonic motions. Fourier theory is based on this fact, where all the complex oscillation modes can be represented by a sum of sine and cosine oscillation modes, with the appropriate frequency, amplitude and phase constants [14]. Oscillation modes of the disc M1 is shown in Figure 3.



a) Mode shape 2 at a frequency of 997.498 Hz

b) Mode shape 3 at a frequency of 1876.78 Hz

c) Mode shape 4 at a frequency of 2804.1 Hz

d) Mode shape 5 at a frequency of 3642.22 Hz

e) Mode shape 6 at a frequency of 4415.79 Hz

f) Mode shape 7 at a frequency of 5157.74 Hz

Figure 3. *Disc modes shapes during braking*

1.3 Analysis of the results for different models of ventilated discs

The results obtained from the analysis performed in the software package ANSYS, using module Static Structural and Modal, are shown in Table 3. To get a better idea of the value of frequencies in each mode, the chart is shown in Figure 4.

Table 3. *Comparative values of the disc modes frequencies*

	2	3	4	5	6	7
M1 [Hz]	997.498	1876.78	2804.1	3642.22	4415.79	5157.74
M2 [Hz]	1002.9	1885.9	2865.3	3734.8	4445.33	5145.4
M3 [Hz]	1211.3	2078.43	3021.14	4098.76	4969.76	5684.95
M4 [Hz]	1014.02	1984.74	2931.59	3715.78	4582.22	5303.68

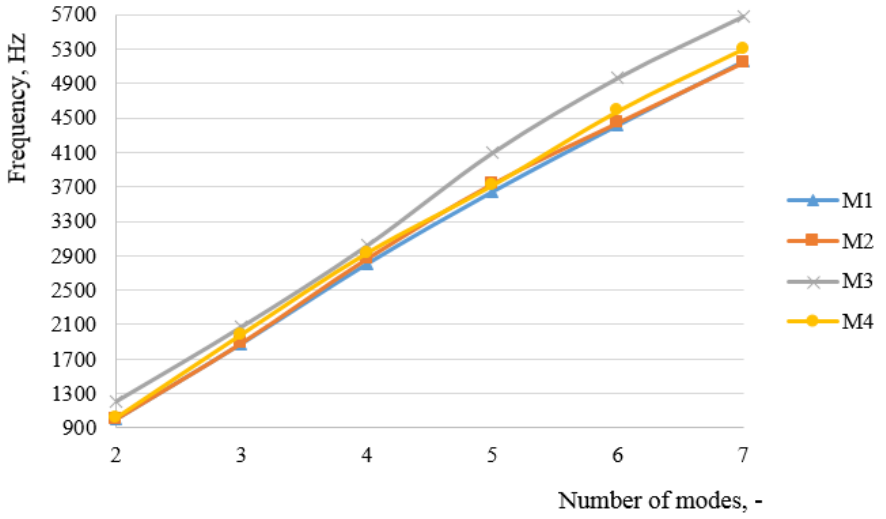


Figure 4. *Chart illustration of modes for different variants of disc*

Analysis of obtained results from Figure 4 shows that at the variant of ventilated disc labeled M3 instabilities occur in higher frequency than in others, while other variants have approximately the same frequencies. The trend line, which indicates a change of the frequency depending on the number of modes, is nearly linear for each model of disc. However, disc with radial ribs labeled M1 have the lowest frequency for every number of modes.

2. CONCLUSION

It is very important that in daily use of vehicle i.e. in the process of braking, noise is reduced to minimum. Noise is one of the factors that affect driver fatigue, which often results in a traffic accident. Vigilance of the driver is very important because in some accident situations he should react on time and in the right way.

Most of the researchers have agreed that squeal noise in the disc brake is initiated by instability due to friction forces, contributing to self-excited vibrations. Modal analysis of brake disc has been carried out for the materials grey cast iron as it is one of the essential parts of the brake system which contributes more in the generation of noise. First seven modes are extracted for the disc for predicting the natural frequencies. The mode coupling is often locked depending on operational conditions and characteristics such as contact stiffness, roughness, adhesive force, etc. Finite element model of the ventilated brake disc rotor was developed to study the influence of various variants of the ribs on the modalities of the brake rotor disc. Conducted analysis has shown that the variant of ribs labelled as M3 has a greater extent, while other variants have a negligible impact on the frequency of analysed modes. It is necessary that in future research to include other elements of the brake assembly in analysis. Of course, in addition, it is necessary to verify results obtained by numerical methods by the experimental research.

ACKNOWLEDGMENT

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SCIENTIFIC VERSUS POLITICAL ECOLOGY

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ABSTRACT: Researches and results in many areas cases are not always based on the laws of nature. The National administrations financially support only researches, which are in line with their policy. The last several American presidents have placed ecology in the centre of their presidential campaign. At the beginning of the mandate the presidents were cancelling all plans of its predecessor and define new targets as the only correct and most effective. Global CO2 emissions from burning fossil fuels have a major impact on the global warming of our planet, say many politicians. Global warming not primarily caused by CO2, more and more often say by scientists and other politicians. Global warming exists but the cause is the Sun, many scientists say. Ecological consciousness and life rules must be at the development base of every country in the world. Identifying the environmental values of each product is the first step in environmental thinking. The basic maxims of sustainable life on our planet are: NOTHING TOO MUCH AND MODERATION IN ALL THINGS.

KEY WORDS: air emission, ecology, energy efficiency, global warming, carbon dioxide

NAUČNA U ODNOSU NA POLITIČKU EKOLOGIJU

REZIME: Istraživanja i njihovi rezultati, u mnogim oblastima, nisu uvek bazirani na zakonima prirode. Nacionalne administracije finansijski podržavaju samo istraživanja koja su u skladu sa njihovom politikom. Poslednjih nekoliko američkih predsednika postavili su ekologiju u centar svoje predsedničke kampanje. Na početku mandata predsednici otkazuju sve planove svog prethodnika i definišu nove ciljeve kao jedine ispravne i efikasne. Globalne emisije CO2 iz fosilnih goriva značajno utiču na globalno zagrevanje naše planete, kažu mnogi političari. Dok naučnici i drugi političari sve češće govore da emisija CO2 nije primarni uzrok globalnog zagrevanja. Ekološka svest i pravila života moraju biti osnova razvoja svake zemlje na svetu. Identifikacija ekoloških vrednosti svakog proizvoda je prvi korak u razmišljanju o životnoj sredini. Osnovne maksima održivog života na našoj planeti je: NIŠTA PREVIŠE I UMERENOST U SVEMU.

KLJUČNE REČI: emisija u vazduha, ekologija, energetska efikasnost, globalno zagrevanje, ugljen-dioksid

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SCIENTIFIC VERSUS POLITICAL ECOLOGY

Radivoje Pešić [1], Stevan Veinović [2]

1. INTRODUCTION

The countries with the most developed economy defined strategic directions of development in all scientific fields. State administrations define politics of development by adopting appropriate action plans. The adopted action plans are sources of the terms. These terms of references are generally in harmony with nature and contribute to the real advancement of society and nature conservation. Adopted policies, sometimes are guided by the interests of the local economy. Researches and results in these cases are not always based on the laws of nature. The National administrations financially support only researches, which are in line with their policy. Therefore, it is often those researchers, who based their research only to the laws of nature, are left without financial support. In this way suitable political scientific elite are created.

As the world faces increasing environmental challenges, people have sought wisdom and inspiration from a variety of sources. One of those sources is the speech which Chief Seattle delivered nearly 150 years ago. Seattle was a Suquamish Indian from the American northwest who delivered a speech in 1854 to Isaac Williams, the Territorial Governor of Washington, as Williams negotiated with him for the sale of land that was to become the city of Seattle (named in the chiefs honour). The speech has been revered by many people for the inspirational message it provides and for the respect for the environment it displays. Regardless of the exact wording of Seattle's speech, it did contain environmental themes [1]. This speech, which speaks of absolutely everything in the natural world, including every insect and pine needles, has pointed the Chief Seattle as the first ecologist. The speech or "letter" attributed to Chief Seattle has been widely cited as a "powerful, bittersweet plea for respect of Native American rights and environmental values". But this document, which has achieved widespread fame thanks to its promotion in the environmental movement, is of doubtful authenticity.

The Clean Air Act was the first major environmental law in the United States to include a provision for citizen suits. Numerous state and local governments have enacted similar legislation, either implementing federal programs or filling in locally important gaps in federal programs. The act were signed into law by President Lyndon B. Johnson on December 17, 1963. The Clean Air Act is the law that defines EPA's responsibilities for protecting and improving the nation's air quality and the stratospheric ozone layer. The last major change in the law, the Clean Air Act Amendments of 1990, was enacted by Congress in 1990 [2].

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The aim of this paper is to analyse the development of US, and UK policy adopted in the field of ecology and energy and to verify these policies with the laws of nature and a scientific ecology.

2. POLITICAL ECOLOGY

2.1 The USA example

The USA has long been leaders in defining development policies of all the sciences, so and ecology. It is therefore of interest to look at the basic policies which are have been proposed and adopted by administrations of the USA presidents in recent decades.

The last several American presidents have placed ecology in the centre of their presidential campaign. At the beginning of the mandate the presidents were cancelling all plans of its predecessor and define new targets as the only correct and most effective.

In 1987, President Reagan signed the Global Climate Protection Act into law, giving the EPA the lead agency role in developing and proposing a "coordinated national policy on global climate change."

The first President from The Bush family (George H. W. Bush, president from 1989 to 1993) has introduced a strategy in which NATO is responsible for the development of different forms of "non-fossil fuels". The main motive is the strategy "Warfare in the territories in which democracy is introduced", because there is difficulty with supplying the war materials: fuels, lubricants and other operating materials. President Bush were sign the UN Framework Convention on Climate Change in Rio, June 1992 [3].

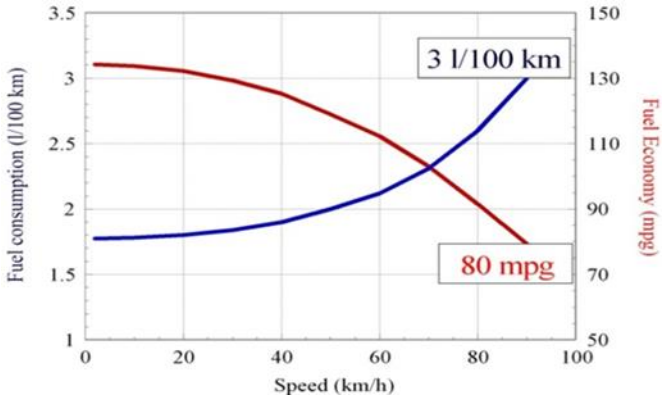


Figure 1. *The main goal of PNGV was to increase fuel efficiency to up to three times from 26.6 (in 1994) to 80 mpg (in 2003)*

On September 29, 1993, the Clinton Administration (Bill Clinton, president from 1993 to 2001) announced the Partnership for a New Generation of Vehicles (PNGV). The partnership consisted of 8 federal agencies, national laboratories, universities, and the USA Council for automotive research (USCAR), which consists of Daimler-Chrysler, Ford Motor Company and General Motors Corporation. According to the PNGV Program Plan, the

program had three key goals: improving manufacturing, implementing new technologies, and developing a "supercar" with three times the fuel economy of a baseline passenger car, while maintaining performance, safety and cost. Specifically, the program planned to increase fuel efficiency to up to three times the average of 1994 family sedans–which was 26.6 miles per gallon (up to 80 miles per gallon, i.e. 3 L/100 km, since 2003) –without reducing performance, safety, or affordability, Fig. 1 [4, 5, 6, 7].

Under the George W. Bush (president from 2001 to 2009) Administration in 2001, the PNGV program was cancelled and funding for this research was redirected to a new program, the "Freedom CAR" program, which will focus on fuel cell vehicles and the related support infrastructure.

The goal of the Freedom CAR and Fuel Partnership is the development of emission- and petroleum-free cars and light trucks. The Partnership focuses on the high-risk research needed to develop the necessary technologies, such as fuel cells and advanced hybrid propulsion systems, to provide a full range of affordable cars and light trucks that are free of foreign oil and harmful emissions - and that do not sacrifice freedom of mobility and freedom of vehicle choice, Figure 2.

Figure 2. *Freedom CAR. President. Georg W. Bush Directs Administration To Take The First Steps Toward Regulations Based On "Twenty In Ten" Goal*

G. Bush in 2007 established aggressive the nation's first comprehensive Renewable Fuel Standard (RFS) program "20-in-10". The "20-in-10" program calls for reducing gasoline usage by 20% in the next 10 years. This reduction is to be achieved by "increasing the supply of renewable and alternative fuels by setting a mandatory fuels standard to require 35 billion gallons of renewable and alternative fuels in 2017" [8].

In the programme G. Bush has directly ordered the EPA agency to change vehicle tests. The EPA has changed its fuel economy testing methods to produce mileage estimates that reflect "real world" driving habits. The new testing process will significantly reduce estimated fuel economy — in some cases up to 25 percent compared to the old testing process. Ironically, EPA has already conducted tests according to new fuel economy tests for years [8].

Figure 3. *Exxon Mobil is the power behind George W. Bush presidential campaign [9]*

Exxon Mobil is the power behind George W. Bush presidential campaign. Exxon Mobil was a large donor of the Republican Party giving over one million dollars, more than all the other oil companies. Eighty-six percent of total contributions went to the Republican Party. But Exxon Mobil, in many ways, kept its distance from the Bush presidency. Mr. Bush mostly delivered on the oil industry's agenda. Yet he seemed to want to distance himself from Exxon Mobil and Big Oil. He even declared in his 2006 State of the Union address that the United States was "addicted to oil." He hoped to be remembered for the long-term investments his administration had made in alternative energy. About Mr. Bush's hope like as presidents of both parties before him, however, he lacked the depth of conviction, the political coalitions and the scientific vision to do more than its wishes. Oil companies does not correspond to a decrease in fuel consumption so politicians are their prisoners, Fig. 3.

In June 2013, President Barack Obama (president from 2009 to 2017) put forward a broad-based plan to cut the carbon pollution that causes climate change and affects public health (Climate Action Plan). Cutting carbon pollution will help spark business innovation to modernize the USA power plants, resulting in cleaner forms of American-made energy that will create good jobs and cut the USA dependence on foreign oil. Combined with the Administration's other actions to increase the efficiency of the USA cars and household appliances, the President's plan will reduce the amount of energy consumed by American families, cutting down on their gas and utility bills.

On August 3, 2015, President Obama and EPA announced the Clean Power Plan – a historic and important step in reducing carbon pollution from power plants that takes real action on climate change. Shaped by years of unprecedented outreach and public engagement, the final Clean Power Plan is fair, flexible and designed to strengthen the fast-growing trend toward cleaner and lower-polluting American energy. With strong but achievable standards for power plants, and customized goals for states to cut the carbon pollution that is driving climate change, the Clean Power Plan provides national consistency, accountability and a level playing field while reflecting each state's energy mix. It also shows the world that the United States is committed to leading global efforts to address climate change.

Summing up his two mandates, Obama has called a meeting of the world's leaders in Paris, in 2015. According to him, that was the first time that world leaders have comprehensively solved the issues of the environment. The departing President of the UN

Assembly, Ban Ki-Moon helped him in all matters, asking the delegates to sign a framework agreement (Fig. 4) before they leave Paris. This agreement shall enter into force in 2020, until when it is necessary to collect $ 80 billion for future environment troubleshooting purposes.

Figure 4. *Paris agreement [10]*

Executive Directive from October 2016 declared it as National energy awareness month [5]. The president Obama urged the people of the United States to adopt clean energy, to renew the economy and make it sustainable by celebrating this month. He noted that the Federal Government is the largest consumer of energy in the United States. It should be emphasized that the Obama administration had pledged to serve as an example in the use of clean energy and high energy efficiency. In the proclamation, it is said that this is a turning point in energy policy, so that the anomalous climate changes cannot be allowed to make chaos. New jobs can be created by developing low-carbon technologies that eliminate the worst effects. Here are the president's remarks to military defence at "Logistics 2016", Fig. 5.

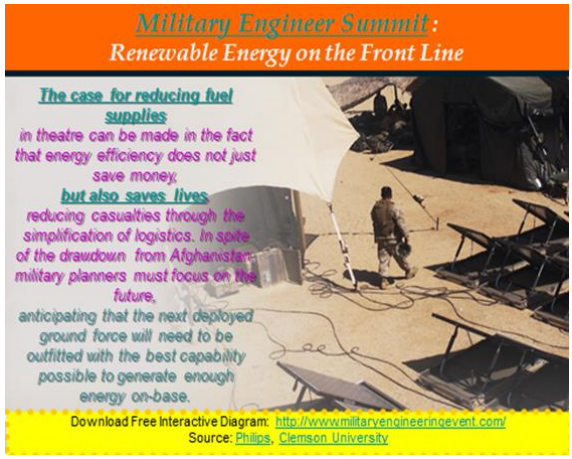


Figure 5. *Renewable energy on the Front Line [11]*

Proclamation: “Better future for the ECONOMY” includes investments in energy efficiency and clean energy [12]:

- application of "GREEN DEFENSE”: energy efficiency as the centre of future planning of operations and infrastructure, and the role of NATO to facilitate such changes
- reorientation to more efficient energy operations: optimization of logistics by relying and extending the possibilities.

Medium and heavy trucks play a key role in the transportation of cargo and passengers and they are the backbone of the US economy. These trucks also play a key role in other areas of society, such as the maintenance of the electrical infrastructures, collecting garbage and improvement of highway systems.

Raising the efficiency of cars in freight transport is vital for reducing oil consumption. During the presidency, Barack Obama gave many optimistic statements about the greater efficiency of passenger cars and trucks and "savings" in power consumption, Fig. 6. Most of them were too optimistic and unattainable.

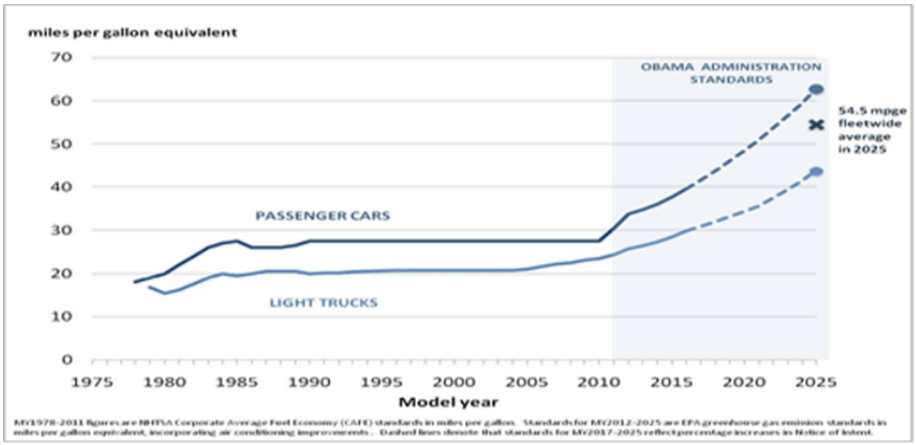


Figure 6. *That’s why one of the very first actions the President took in office was to direct the Environmental Protection Agency and the Department of Transportation to work with the auto industry to develop new fuel economy standards for cars and trucks*

That is why one of the first President’s orders was to direct Environmental Protection Agency and Department of transportation to work with the automotive industry on introduction of new standards on fuel economy program for light-duty vehicles and trucks [13, 14]. New standards for cars and light trucks, compared to models from 2011, that should be implemented by 2025, represent the most rigorous standards in the history of the required fuel savings. Within this, the first national program, the average fuel consumption for cars and trucks will be almost cut by half, if the average performance equivalent to 54.5 miles per gallon is reached by 2025, Fig. 6 and Fig. 7.

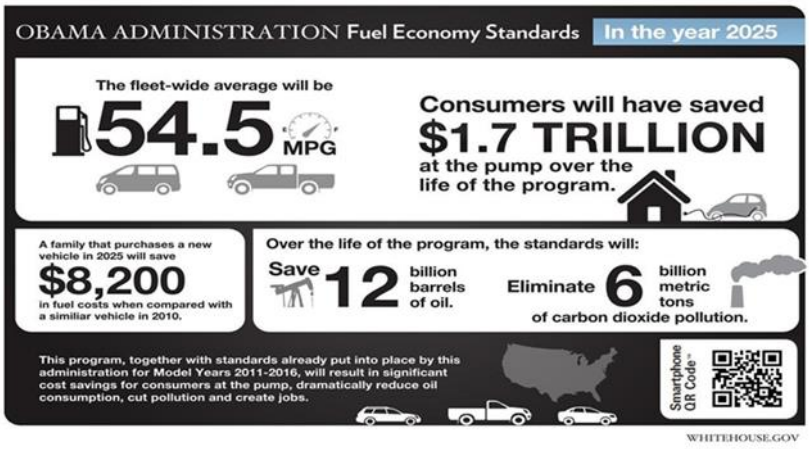


Figure 7. *The President also established the first-ever fuel efficiency and greenhouse gas standards for medium- and heavy-duty vehicles, covering model years 2014 through 2018*

The President has also programmed the first standard for fuel efficiency and greenhouse gases reduction for medium and heavy vehicles, by comparing models from 2014 improved by 2018. During the life of these vehicles, trucks and buses, oil consumption will be reduced by projected 530 million barrels and gas pollution emissions by about 270 million tons, saving the vehicle owners and operators about 50 billion dollars in fuel costs.

According to this project, the super tractors will improve the efficiency by more than 100% as relative increase compared to trucks from year 2009 (from 5.8 to 10.7 mpg), by maintaining excellent technologies for cost-efficiency and performance (Source: Office of energy efficiency, March 9th, 2016), Fig. 8, [15, 16].

Figure 8. *The US class 8 tractor trucks for heavy working conditions with Cummins engines and Peterbilt equipment with intention to achieve 10.7 miles with one gallon under real driving conditions. The truck was inspected by the Department of energy (Source: Photo Sarah Garrity)*

Volvo Press Centre Division: "We work continuously on the development of energy-efficient vehicles", says the president and chief executive of Volvo trucks, Klaes Nilsson. New Volvo truck concept is aimed at 30% reduction in fuel consumption compared to the typical trucks of such classes. Improvement of efficiency of Volvo trucks comes down to an aerodynamic design and weight reduction (source: Volvo 15, 16]).

Following Donald Trump's swearing-in (January 2017), the White House Web site was quickly updated to completely eliminate the phrase "climate change" replacing it with Trump's "America First Energy Plan,", and the Trump administration has instructed the E.P.A. to remove a page about climate change from its Web site [17]. It is not unusual for a new president to order changes to agency Web sites, or to temporarily suspend their public communications until they are brought into line with administration policy. But the executive actions taken by president Trump in his first days in office have raised alarms for the speed with which he has sought to erase Barack Obama's environmental legacy and the unusual scope of the changes [17, 18].

U.S. EPA, in February 2017, recall some section of the Clean Air Act, and regulations for the LD sector, and program for light-duty vehicles and light-duty trucks [19]

President Donald Trump decided that the United States will withdraw from the landmark Paris climate agreement. Trump also decided he would start talks to re-enter the accord with what he called a more "fair" deal, but was immediately rebuked by several European governments. The decision sets the world's largest economy apart from almost all other nations on Earth, and moves in opposition to many large American companies, as well. Always a showman, Trump announced the decision in a heavily teased event at the White House Rose Garden, where administration officials and conservatives applauded the move. "In order to fulfil my solemn duty to protect America and its citizens, the United States will withdraw from the Paris climate accord, but begin negotiations to re-enter either the Paris accord or an entirely new transaction on terms that are fair to the United States, its businesses, its workers, its people, its taxpayers," Trump said [20].

2.2 The UK example

Since 2005 Emissions of greenhouse gases have been subject to regulation under a market based mechanism known as the EU Emission Trading Scheme (ETS). This European wide policy regulates roughly half of all emissions in the EU. A finite number of allowances to emit are created and distributed. Participating installations must then surrender allowances to match the emissions they produce. Those who can cheaply and easily reduce their emissions can sell spare allowances to those who find it harder or more expensive to do so. The balance of supply and demand for allowances creates a traded price for carbon [21].

The Carbon Price Floor (CPF) is a UK Government policy implemented to support the EU wide Emissions Trading System (EU ETS) which places a price on greenhouse gas emissions. It does this by requiring heavy energy users to acquire permits for every unit of greenhouse gases they emit. These permits are called emission allowances.

Britain's decarbonisation policies are not the same as other European countries. They are much more aggressive. When, in 2007, Germany proposed the EU adopt renewable energy targets, to the horror of the Treasury and Alistair Darling's Department of Trade and Industry, Tony Blair gave Britain the most aggressive wind and solar targets of any member state. With Blair gone, Gordon Brown's government rejected proposals for a unilateral carbon price floor. The idea was to prop up the price of carbon allowances credits

under the EU's Emissions Trading Scheme. This sensible approach was abandoned by the Coalition government. To show climate leadership, the Coalition Agreement promised a carbon price floor, which duly came in George Osborne's 2011 budget [22].

Following the implementation of the Carbon Price Floor in the UK, the European Commission considered, but ultimately rejected, a similar system to reform the EU ETS. This option was also considered by France but the proposal has been dropped. Thus way, UK energy generators will face carbon costs six times higher than their European counterparts. This poses an interesting dilemma for Treasury as it will result in more revenue than it might otherwise expect from the EU ETS, but imposes greater cost on British industry compared to European competitors [21, 22, 23].

In fact, the impact of the carbon price floor on electricity costs is greater than the sums reaped by the Exchequer, as it gives investors in low-carbon capacity, especially nuclear, the ability to price up to the floor. Rather like airport duty-free shops, it turns them into quasi-tax collectors lining their own pockets [22].

This huge annual windfall helps explain how in 2015 the owners of Britain's nuclear power stations collected £994m in operating profits. Over the same period, the Big Six's gas and coal-fired power stations, which generated 65% more electricity than nuclear, racked up £405m in operating losses. The carbon price floor is the principle reason why coal generation, Britain's cheapest source of electricity, is being forced off the grid, even though Germany expects to keep operating its coal-fired power stations until 2040 [21, 22].

Driving down energy consumption and pushing up high-fixed-cost generating capacity is a formula for ever-rising electricity prices? Between 2013 and 2015, the price of fossil fuels used by the Big Six (G6) to generate a megawatt hour (MWh) of electricity fell by 20.1%. Network costs rose by 9.8% and green and other government levies rose by a whopping 26.6% per MWh of electricity supplied by the Big Six. While the rest of the world enjoyed the benefits of plunging fossil fuel prices, electricity prices in the UK rose by 4.2%. This is not the fault of the Big Six. The blame rests fairly and squarely on government policies [21, 22].

Therefore, headlines in newspapers are becoming more and more frequent, such as: "False claims on low-carbon energy are damaging UK" [21].

3. CRITICAL REVIEW OF POLITICAL ECOLOGY

The critical verification of political ecology is based on the J. Robert Oppenheimer's words: "We do not believe that any group of people is sufficiently or wise enough to work without supervision or without criticism. We know that the only way to avoid the mistake is to discover it, that the only way to It reveals it freely to inquire, we know that it will be wrong to reveal and undermine in secret" [24].

In the following text, during analysing the attitudes of the political ecology, some questions will be asked and some answers will be get.

The misuse of ecology is the introduction of the concept of "renewable energy resources", the "green economy" and many "eco" prefixes with the wrong content. Military war strategies impose the development of these areas. It is well known that countries rich with raw materials do not have well-developed infrastructure [25, 26, 27]. This is why "renewable energies" like: Sun, wind, hydro energy and biomass are very important in the war. All projects that receive scores of NATO-importance are due a large financial backing.

A better future of the economy and the nation needs investments in energy efficiency and clean energies. Good financial support for research and development of the energy sector will help not only to protect the environment and support the community, but will also contribute to the global competitiveness and national security. Innovations in energy technologies reduce dependence on oil, boost the economy and reduce the danger of pollution that causes climate change [16, 28].

Figure 9. *More and more often are heard the other side of the story emissions of carbon dioxide*

Geophysics is a natural science that deals with physical processes and the physical characteristics of Earth and its space environment, using quantitative methods for their analysis.

There is no convincing scientific evidence that anthropogenic release of carbon dioxide, methane, or other greenhouse gasses is causing or will, in the foreseeable future, cause catastrophic heating of the Earth's atmosphere and disruption of the Earth's climate. Moreover, there is substantial scientific evidence that increases in atmospheric carbon dioxide produce many beneficial effects upon the natural plant and animal environments of the Earth. Oregon Petition, from the Oregon Institute of Science and Medicine, signed by over 17,000 international scientists including more than 2000 of the world's leading climatologists, meteorologists and planetary / atmospheric scientists [29].

Carbon Dioxide currently at 370 ppm, for it to be dangerous it would have to be at 15,000 ppm. This could not be reached even if every fossil fuel was burned. Thousands and thousands of studies show that higher levels of CO_2 are good for plants. Many scientists believe plants still are not getting enough CO_2. Tomato farmers using exhaust from electricity to grow their tomatoes. Vegetation loses less water under higher CO_2 levels, meaning vegetation in drought prone areas will live longer and produce more. Rice (the most eaten food in the world) was shown to increase mass and use less water with higher

CO_2 levels. Meaning the most important food in the world highly benefits from CO_2 increase, Fig. 9.

Global warming not primarily caused by CO_2, says Donald Trump's environment chief Scott Pruitt [30].

4. LIFE OR SCIENTIFIC ECOLOGY

As it is well known, life on Earth is possible due to the existence of "natural greenhouse effect". Svante Arrhenius has developed a theory to explain the ice age, and in 1896, he was the first scientist who was trying to explain how changes in the level of carbon dioxide in the atmosphere can change the temperature of the surface by greenhouse effects. In its original form, the law Arrhenius law of "greenhouse gases" is as follows: If the amount of carbonic acid [H_2CO_3] increases geometrically, the temperature will increase by arithmetical progression. Equivalent formulation of Arrhenius "greenhouse gases" dependence is still used today.

The natural greenhouse effect phenomenon, primarily water vapour, H_2O, carbon-dioxide, CO_2, and some other gases (such as methane, CH_4, nitrogen oxide – NO_x and ozone, O_3) allows sunlight to penetrate to the Earth:

- to light the Earth,
- to maintain photosynthesis that enables the life of flora and fauna, and
- to keep infrared heat in the atmosphere.

All of these three phenomena sustain our planet as moderately warm, which is a condition for the normal physiological functions of all living organisms. The absence of greenhouse gas emissions would reduce the temperature of our planet similar to other lifeless planets of our solar system [26, 27].

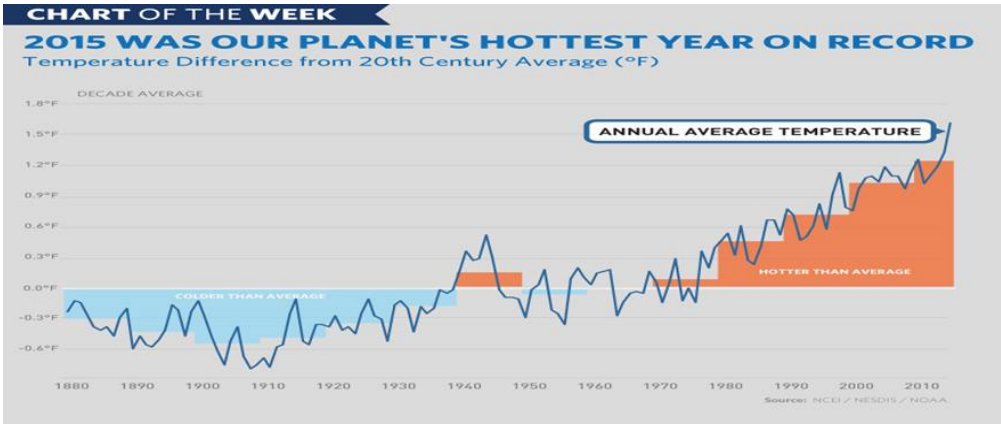


Figure 10. *Chart of the week: 2015 Was Earth's Hottest Year on Record January 25, 2016 at 3:01 PM ET by wh.gov/climate*

Measurement of global average temperature of air had started in the late 1800's. According to National Oceanic and Atmospheric Administration (NOAA), in 2015, global average temperature of surface air was 1.62 °F (0.90 °C) above the level in the 20th century or the highest of all levels from 1880 to 2015, overcoming the previous record in 2014 by 0.29 °F (0.16 °C), Fig. 10. According to NOAA, this is the largest overstepping of mean annual global temperature [31]. Since 2001, our planet has witnessed 15 of 16 hottest years ever recorded. If we want to avoid the disastrous consequences of climate change, we need to dedicate ourselves to this problem now.

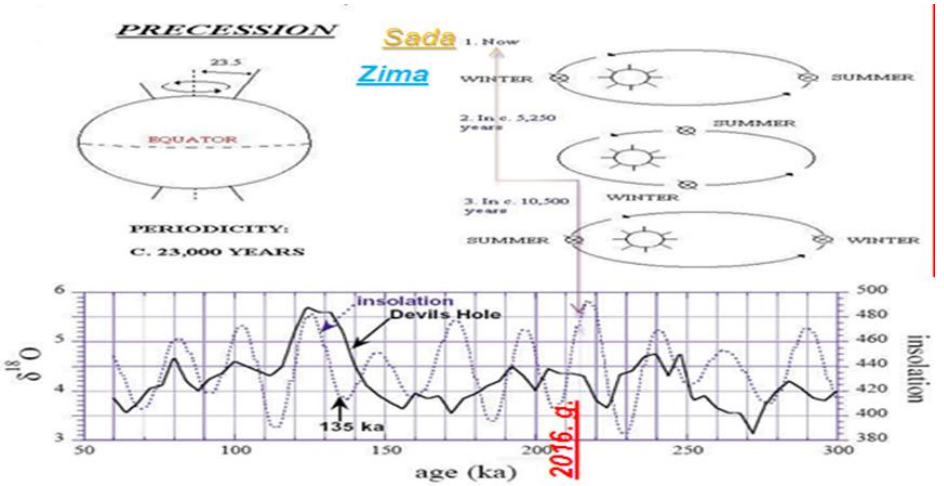


Figure 11. *For about 50 years M. Milanković theory was largely ignored*

The cosmic laws define global relations. For a more detailed understanding of global relations, one should, once again, take a look at the work of our "cosmic" scientists, Milutin Milankovic [32, 33]. Simplified definitions of environmental protection say that the basic problems are:

- Global warming,
- Thickening of the Earth's layers (by three- and multiple-atomic gases) and future lack of oxygen in the atmosphere!
- Technologies of environmental protection are the ones that are conducted with the lowest consumption of oxygen - without oxygen, there is no life,
- All human activities, at the same time and every day, are changing genetic basis for sustaining the life on Earth.

The future is similar to Venus and Mercury because they are too close to the Sun and overheated. Other planets are far from the Sun and too cold. While reading the standpoint of the President Obama, Fig. 4, it seems that he looked at the lists of M. Milankovic, Figure 11.

Reserves of fossil fuels are not sufficient, Fig. 12. There is a visible alternative for vehicle drive - electrical motors, Fig. 13. The fact that Nikola Tesla's ideas of remote and

wireless transmission of energy are not remembered nor materialized is not an obstacle to constantly try such a thing.

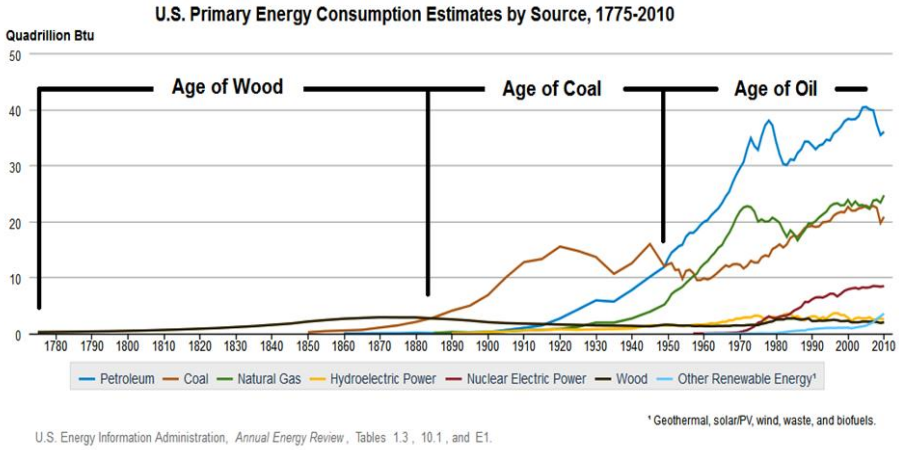


Figure 12. *USA primary energy consumption*

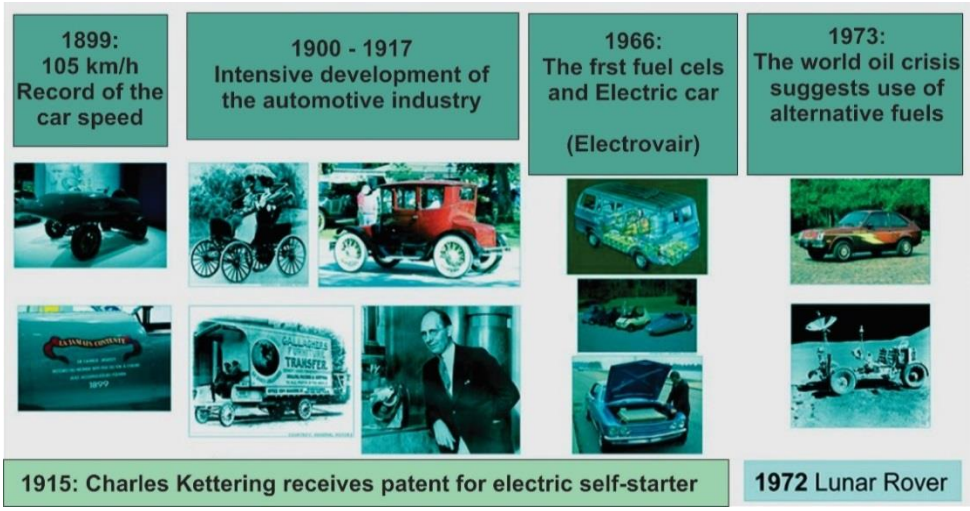
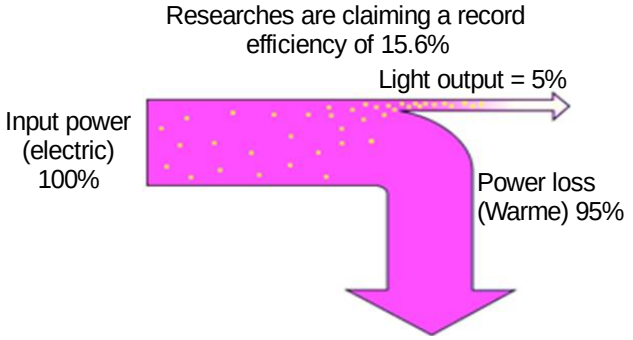


Figure 13. *Energy voltage in vehicles between 12 – 48 – 96 – 400 - 800 V*

Battery power for vehicles had existed 100 years ago, until mass production of internal combustion engines and fossil fuels had reduced it to individual cases, Figures 14 to 16.



$$\eta = \frac{P_{Useful}}{P_{Input}} \cong 5\%$$

Figure 14. *Solar energy: Researchers claim that record efficiency of 15.6% is possible in laboratory conditions*

Figure 15. *Wind energy: without efficient energy balance, there are no eco-grades*

Figure 16. *BIO ENERGY: the biofuel system has aggravated rather than helped to mitigate global warming, even for systems where the life-cycle analyses indicate a positive influence on net greenhouse gas emissions*

"Hydropower vision" believes that the rise in power from hydroelectric plants, from 101 GW capacities in 2015 to nearly 150 GW by 2050, is realistic in the United States. World reserves are still around 2%.

Bio energies do not help in mitigation of global warming, even for systems where the life-cycle analysis indicates a positive influence on net greenhouse gas emissions.

5. CONCLUSIONS

Human activities leave lasting consequences on the Earth and the environment! There is no "ecological life", but only "ecological behaviour". There is no "green energy", but only a reasonable engaging of energy sources with a lot of eco-friendly concessions. The overall environmental pollution of air, water and land leads to compromising the genetic basis by uncontrollable changes around the world on which our planet rests.

Ecological consciousness and life rules are at the base of every country in the world. Identifying the environmental values of each product is the first step in environmental thinking. Once upon a time, the companies had rarely respected it, but that usually eliminates the huge, amazing amount of waste. The basic maxims of sustainable life on our planet are: NOTHING TOO MUCH AND MODERATION IN ALL THINGS. (Quote: ancient Greek Delphi).

To our knowledge, our language does not contain the correct scientific definitions of words on the meaning of energy sources "renewability" or "repetition". Terminology emphasizes the extreme differences when it comes to the environment. Technically, all sources of energy are repeated and are not renewable. It is the question of different time intervals – the important distinction between renewable and non-renewable sources of energy is the speed of their repetition. Definition of sources of energy may be the only such repeatability, or reintegration should be regarded integrally, with appropriate technologies and plants for their transformation. For example, unmanaged installation of wind power plants or solar panels leaves us immediately with no usable land, before all fossil fuels are effectively spent. In addition, windmills and solar panels are heating up the surrounding area and are working with very low efficiency in terms of preserving the environment!

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DESIGN FOR RECYCLING – THINKING OF THE END AT THE BEGINNING

Dušan Gruden[1]

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ABSTRACT: Regulations of the European Union are demanding that re-use of materials should be taken into account already in the design phase of new vehicles and to provide instructions about exploitation of the old cars. When engineering a car, every part of the vehicle is analysed in terms of ecological criteria: "the possibility of re-use of materials", "convenience for recycling" and "critical materials". The primary principle of "Design for recycling" is using a closed circuit of materials. Recycled material must fully correspond to the new material in all its properties. Analysis of different materials shows that with the increasing application of recycled materials substantial savings in energy consumption and raw materials can be achieved. Selection of plastic materials plays a very important role in the engineering of the car taking into account the recycling. Labelling the plastic allows its clean sorting and re-use. In addition, an important criterion is easy disassembly of the parts to be used again. Car producers are obliged to prepare manuals for disassembling for each vehicle.

KEY WORDS: recycling, design, selection of materials, energy savings, disassembling, LCA

KALIBRACIJA UREĐAJA ZA KONVERGENCIJU KORIŠĆENJEM FOTOGRAMETRIJE

REZIME: Propisi Evropske Unije zahtevaju da se ponovna upotreba materijala treba uzeti u obzir u fazi projektovanja novih vozila i da se pruže upustva ekspolatacije starih votila. Prilikom projektovanja automobila, svaki deo vozila se analizira u smislu ekološkog kriterijuma: “mogućnost ponovnog korišćenja materijala”, “pogodnosti za reciklažu” i “kritičnih materijala”. Primarni princip “Dizajn za reciklažu” koristi zatvoreni krug materijala. Reciklirani materijal mora u potpunosti odgovarati novom materijalu po svim svojstvima. Analiza različitih materijala pokazuje da se uz sve veću primenu recikliranih materijala može ostvariti značajna ušteda u potrošnji energije i sirovina. Izbor plastičnih materijala igra veoma važnu ulogu u inženjeringu automobila uzimajući u obzir recikliranje. Označavanje plastike omogućava njeno čisto sortiranje i ponovnu upotrebu. Pored toga, važan kriterijum je jednostavna demontaža delova koji će se ponovo koristiti. Proizvođači automobila su obavezni da pripreme priručnike za demontažu za svako vozilo.

KLJUČNE REČI: kalibracija, etaloniranje, podešavanje točkova, merilo, fotogrametrija

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DESIGN FOR RECYCLING – THINKING OF THE END AT THE BEGINNING

Dušsan Gruden [1]

1. INTRODUCTION

Average life of cars in the European Union amounts between 12 to 14 years. After this service life, a question arises what to do with an old car? What to do with a car that is frequently called "automotive rubbish"? Around 20 to 22 million cars in the world and around 7 to 9 million cars in the European Union reach this status every year.

Efforts of modern society to reduce a negative effect of human activity on natural environment do not leave behind the end-of-use cars ("End of Life Vehicles", ELV). In October 2000, a regulation regarding end of life vehicles was issued in the European Union, which has become obligatory for all member states since 2002 [2]. Provisions of this regulation demand that reuse of the used materials should be taken into account already at the design stage of the new vehicles. They also contain instructions on exploitation of the old cars.

For all new cars let into traffic after January 1st, 2006, it must be proved that 85% of average vehicle weight can be recycled or re-used in other way, Figure 1.

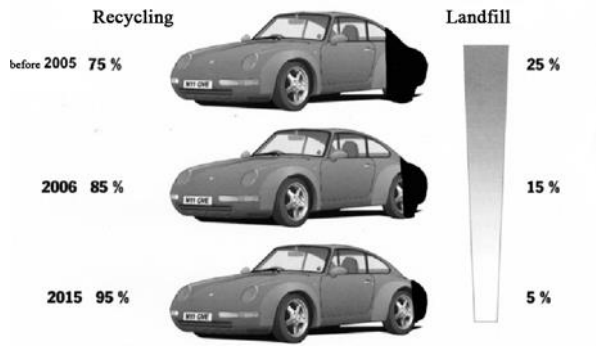

Figure 1. *Recycling of the old cars*

Only 5% of it may be energetically (thermally) re-used, while 15% of vehicle weight may be deposited at landfills. Since January 2015, a re-use quota has been raised to 95%, 10% of which may be energetically re-used, while 5% may be deposited at landfills.

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These goals can be achieved only if demands regarding preservation of the human environment and especially on vehicle recycling are already defined in the phase of definition and car design, alongside with technical and economic parameters.

2. LIFETIME OF A VEHICLE

After the decision on building a new vehicle is reached, analyses and prognoses on future market development and economic, social and ecological developments during the planned time for production of the given model are conducted.

In long-life products like cars, the main challenge for designers is that decisions on car recycling must be made in the phase of definition and generation of the vehicle, although the act on recycling would be valid after 15 to 25 years, when the recycling technology might be altogether different than assumed at the vehicle design phase [3].

It takes 3 to 4 years to develop a new engine and a new vehicle, Figure 2. This means that, at least 3 years before the beginning of production, the legal regulations that would be set before the car at the time it is let into traffic must be known.

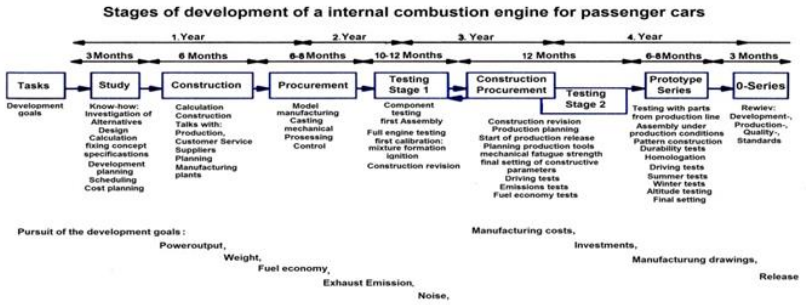

Figure 2. *Phases of IC engine development (Source: Ampferer)*

Production of one model lasts 4 to 8 years, while its average traffic life is 12 to 14 years, Figure 3.

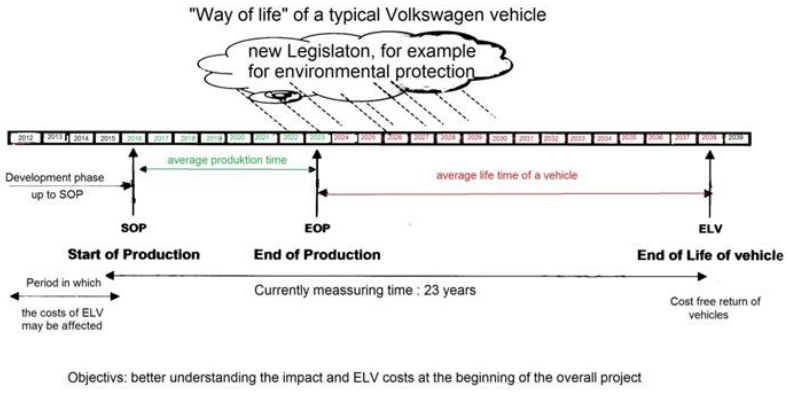

Figure 3. *The duration time of one model of vehicle (Source: VW)*

Around 20 to 25 years pass, from the concept design, through beginning of production to car recycling. The automotive producers must be active during all that time. In addition to market development, they must take care also on technological development and development of legislative during that period.

The automotive producers make only 30% to 40% share of car value. The greatest share of car value (60% to 70%) is made by suppliers industry, Figure 4.

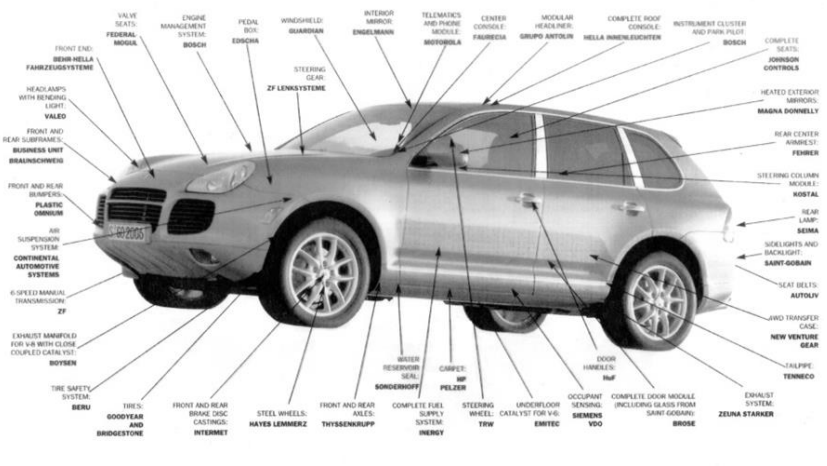

Figure 4. *Suppliers for Porsche Cayenne*

That is why the suppliers industry bears a large share of responsibility in the achievement of the objectives of the automotive industry, including requirements in terms of ecology and especially recycling the cars.

3. DESIGN FOR RECYCLING

Car manufacturers are required to construct their vehicles in accordance with the legal regulations in terms of safety, fuel economy, exhaust and noise emissions, and in terms of economic feasibility, production costs, as well as many other features, Figure 5.

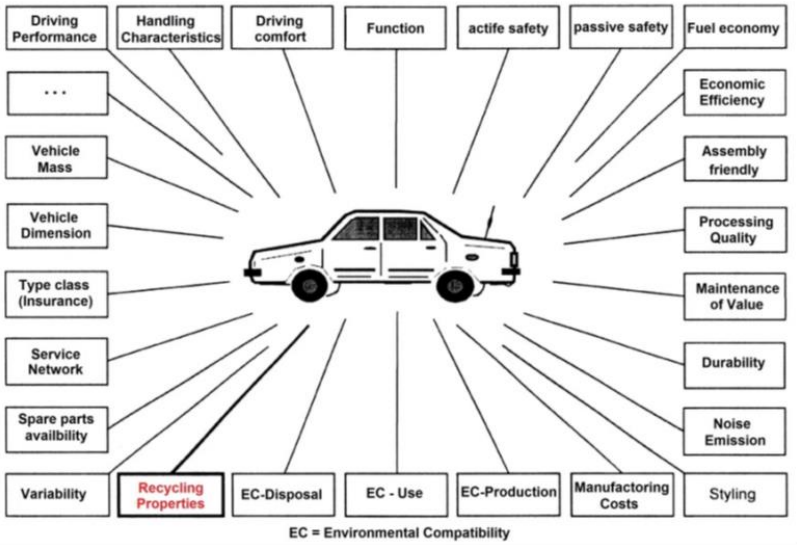

Figure 5. *Requirements in car design (Source: BMW)*

Optimization of all requests that are put in front of car development, leads to decisions on the selection and implementation of certain materials in the design of the vehicle [4, 5].

Responsibility of the designer is not completed by the fulfilment of the requirements in terms of functionality, production processes and cost-efficiency of products. It extends to a "comprehensive product liability" during the entire lifetime of the product, until the end of its use, or its re-use in the process of recycling or ecological removal from the traffic.

During design, every part of the vehicle has to be tested in terms of environmental criteria: "the possibility of re-use of the material", "convenience for recycling" and "critical materials", together with the testing concerning the technical and economic benefits.

Most manufacturers have their own, specific regulations for recycling, which must be taken into account in the design of the vehicle. These regulations are obligatory for designers from both the automotive industry and the suppliers industry. In this context, it is important to point out the "International Material Data System" (IMDS), which was developed in cooperation between almost all world automotive manufacturers and their suppliers industries [6]. The IMDS's goal is a precise description of the chemical composition of all parts of the car, because, in order to fulfil the request of the European regulation on recycling of 95% of the vehicle weight, the chemical composition of the product must be known.

The focus of vehicle design with regard to recycling is made of the selection of materials and technique for bonding parts and assemblies.

The following recommendations are given to the designers for the realization of "recyclable design“:

- As small as possible application of different materials, in order to be more easily identified and sorted for recycling.
- Preferably, apply not only recycled materials, but also materials containing recyclates.
- Problematic substances should be limited to the required minimum. Avoid the substances that can be dangerous for production or for recycling.
- The number of different bindings and applied adhesives should be reduced to the essential minimum.
- Select the bindings that are eventually easily disassembled at the end of the use of car.
- Plastic materials should be marked according to ISO norms.

4. SELECTION OF MATERIALS

Recycling of cars is closely related to the number and type of applied materials and simplicity with which materials can be identified and separated.

Number of applied materials should preferably be as small as possible. In ideal case, all parts of an assembly should be of the same material, or from materials that are chemically related.

The primary principle of "design for recycling" is to organize and use the material recirculation. Recycled material must have characteristics that fully correspond to those of a new material. Safety and quality of the vehicle must not be victims of recycling.

The so-called problematic and hazardous materials, that can be dangerous to humans, environment or facilities during processing and application, must be avoided. If this is not possible, then they must be clearly marked and must be easily disassembled. Materials and elements like e.g. asbestos, lead, mercury and CFCs are marked as problematic and should be avoided because of endangering the environment or because of their toxicity. The European regulation on the recycling of cars has prohibited the application of lead (Pb), mercury (Hg), cadmium (Cd) and 6-valent chrome (CrVI) in cars since January 1st, 2005. Some exceptions are allowed.

Since 2007, the European policy on chemicals, REACH (Registration, Evaluation and Accreditation of Chemicals), has been trying to bring more clarity to the risks of application of different chemicals in the production [7].

Since December 2008, all chemicals in the European Union must fulfil the requirements of the regulation on registration, labelling and packaging of materials and mixtures (CLP - Classification, Labelling and Packaging). In addition, the world policy GHS – Globally Harmonized System of Classification and Labelling of Chemicals must be taken into account.

The desired effect of recycling is to reduce the consumption of raw materials and energy.

Specific energy, which is needed to produce some material, is divided into primary and secondary energy. Primary energy includes all of the consumed energy required to produce a new material from raw materials obtained from natural sources and for further processing, as well as all the energy spent in transport in the course of this processing. Secondary energy is the sum of all energies needed to obtain a material from recyclates with the same characteristics as a "new" material.

Specific primary and secondary energies for a number of materials that are used in the automotive industry are presented in Table 1.

Table 1. *Primary and secondary energy for different materials*

	Primary energy kJ/kg	Secondary energy kJ/kg
Steel	40.000	18.100
Iron	34.000	24.000
Aluminium	190.000	26.700
Glass	30.000	13.000
Lead	41.100	8.000
Copper	1000.000	45.000
Rubber	67.600	43.600
Polypropylene	74.300	42.300
Polyvinylchloride	65.400	29.300
Polyester	95.800	50.000

Energy analysis of production of different materials indicates that, with the increased application of recycled materials, the substantial savings in energy consumption can be achieved [8].

Different impurities often make it difficult for recycled material to have the same characteristics as the "new" material. However, where it is technically possible, the recycled material should always have preference over the "new" material.

5. PLASTIC MATERIALS

Plastic materials (plastics) are playing an increasing role. Their good workability, use-value and, especially, their low weight, meet the requirements of the automotive industry. In modern cars, their share is more than 15% of the vehicle weight. Hundreds of different plastic materials are applied in modern cars. Selection of these materials plays a very important role in automotive design, taking also into account the recycling. From the very beginning, a proper selection of plastic materials for all parts of the car must be made and, at the same time, to use the fewest possible number of different plastics.

The plastic parts should be, in principle, made of only one material. As it is not possible, then chemically distinct polymers should be carefully selected. Not all plastic materials are compatible with each other, Figure 6. Selection of compatible components from one group of materials can significantly simplify recycling of the plastic materials.

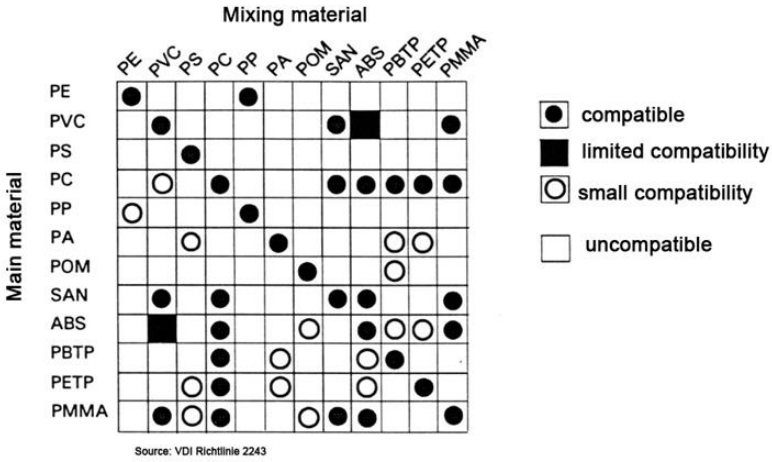

Figure 6. *Compatibility between different plastic materials*

Labelling has an important role in recycling plastics, allowing for their clean sorting and re-use at high technical level. In the European Union, a Directive 2000/53/EC on labelling of parts and materials is in effect. Also, ISO 1043, ISO 11469 and ISO 1629 norms, as well as VDA-260 and SAE-J 1344 policies are valid for labelling and identification of the parts of the vehicles whose weight exceeds 100 g.

Since the mid-90's of the last century, the car and supporting industries have been developing concepts for the application of recyclates of plastic materials in the design of new vehicles [9]. In modern cars, the share of plastics from recyclates amounts between 10% and 15%, Figure 7.

Figure 7. *Plastic parts from recyclates in Porsche 911 Turbo*

The downside of composite materials used in design of cars - the inability of their material recycling, has reduced a great deal the original huge interest for these materials.

In addition to metals, plastics and glass, the automotive industry increasingly applies renewable resources, raw materials, from nature [10]. Beside leather for interior and rubber for the tyres, natural fibres from wood, cotton, jute, bamboo, flax, coconut, etc., gain more and more attractiveness for the automotive industry. Natural fibres, as high-quality materials, are often an alternative to plastic, synthetic fibres, Figure 8.

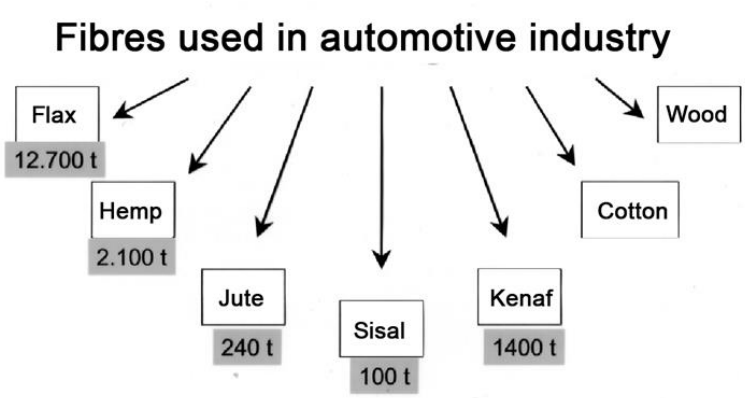

Figure 8. *Renewable raw materials in car construction (Source: Audi)*

Summarized, the automotive designers can be given the following recommendations for the selection of plastic materials:

- Make as many parts as possible of only one material.
- Construct the assemblies from chemically compatible materials.
- Provide ability for recycling and re-use of plastic materials
- Enable their re-use at as high technical level as possible.
- Label all parts according to the existing standards.

6. DESIGN FOR DISASSEMBLING

An important criterion for designing the recycling-ready vehicles is easy disassembling of the parts that should be further applied. The stipulated recycling quotas for old cars can only be achieved if separation of aggregates and assemblies and their clean sorting are enabled.

Automotive producers are obliged to prepare also manuals for vehicle disassembling for each vehicle. Criteria for assessment of disassembling are the time required for disassembling as well as weight and physical-chemical composition of disassembling parts. The time required for disassembling especially burdens the costs of the entire recycling process.

Known rules for the assembly of the vehicle cannot be applied without further notice to their disassembling. Disassembling of parts and material separation need to be as simple as possible and to be quickly implemented.

Elements connecting the components and assemblies that can be re-used must enable disassembling without damage. This request is known as "manuals for reparation" goal in vehicle design.

With requests for recycling of other materials, the primary goal is to obtain as huge as possible quantities. Here, it does not matter whether the part is damaged or not. It is important to gain as much material in the shortest possible time, so that "violent" disassembly may be predicted.

A basic prerequisite for easy disassembly is easy access to the parts that are disassembled – without applying special tools. This includes the careful selection of technique of connecting the individual parts. Figure 9 shows the various connecting elements and their suitability for recycling.

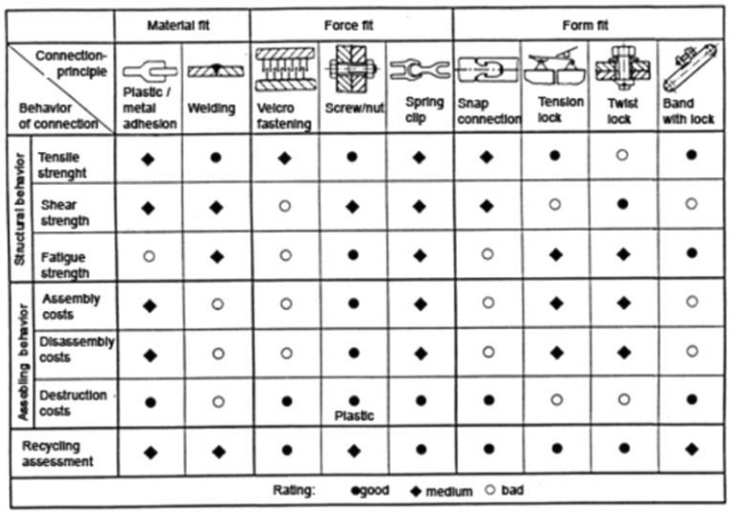

Figure 9. *Assessment of suitability of different connection elements for recycling*

A bonding technique, which cannot easily be disassembled (like welding, gluing, riveting …) should be avoided where possible. Instead, easily disassembled bonds should be applied (sockets, clips, bayonet-connections ...). For easy disassembling, deliberately weakened spots, designed to fracture, are also suitable.

Assemblies containing liquid working fluids must have suitable possibilities to drain the fluids. The "drying" of the vehicles is one of the first steps in vehicle recycling. The design must already take into account that the reservoirs of oil for engine, gearbox, differential and power steering are easy accessed and that they have the oil drain plug always at the lowest position.

The basic feature of recycling-ready design consists of selection of materials suitable for re-use and design suitable for disassembling.

To summarize, there are three available ways to meet regulatory standards and reduce the amount of waste, which occurs at exclusion of old cars from the traffic:

- design for recycling,

- re-using as many parts as possible and recycling the rest of materials and
- energy use of car parts, which can't be used as materials.

These three ways are not mutually exclusive, but complement each other.

7. PRODUCT'S LIFETIME

It is generally valid, that twice-long product usage reduces the annual amount of waste by 50%. Assemblies and spare parts need to be engineered and manufactured to have as long as possible lifetime, to be easily disassembled and, if it is technically possible, to continue to be used. The best preservation of product value, from the standpoint of saving of raw materials and energy is achieved by parts repair. Re-establishment of function and modernization of parts and assemblies are important elements of products recycling. In that way, savings of about 30% in materials and 40% in energy and reduction of time needed for production of about 140% are achieved in comparison with the creation of new product.

The price of generally repaired vehicle engine is about 40% less than that in a new product.

Only, even with prolongation of the time of use and with the application of recycled materials, the problem of removing old cars is not resolved, but only moved in time. This problem occurs again when the product made of recyclates finally does his part and definitely must be removed from traffic.

8. LIFE CYCLE ASSESSMENT

The total life cycle of a car encompasses its development, production, exploitation and, at the end of the lifetime, recycling of old vehicle. For a long time, this cycle was considered as a closed, circular system.

The comprehensive instrument for assessment of environmental impact of the product is the ecological balance or Life Cycle Assessment (LCA). All parts of the car are analysed with respect to the resulting consumption of raw materials and energy during their emergence, as well as to the resulting emissions and other environmental impacts in the course of the entire cycle of creation and use of the product – "from the cradle to the grave", Figure 10 [11].

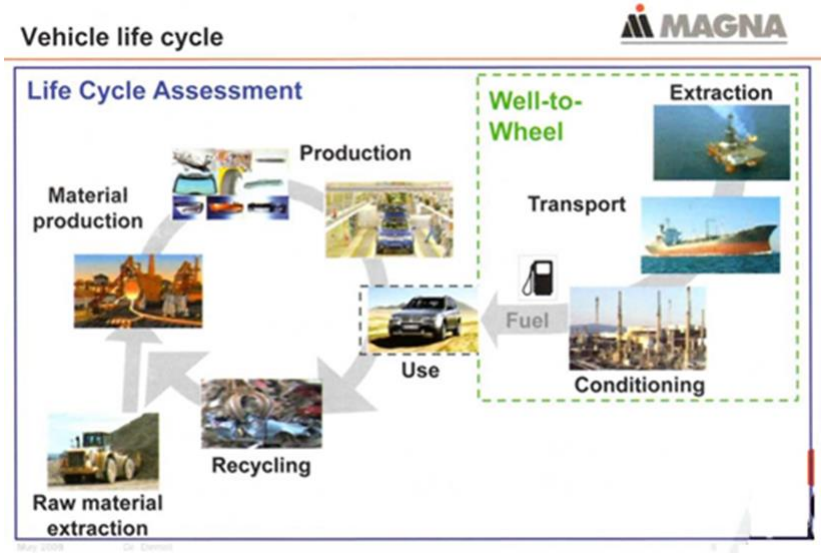

Figure 10. *Life Cycle Assessment („from the cradle to the grave “)*

According to the ISO 14040 series, Life Cycle Assessment is defined as "Systematic collection and analysis of inputs and outputs of material and energy into a system and related influences on the environment, which emerge in production and during functioning of the product in the course of its life cycle".

In addition to the ISO 14040, the European Commission has passed the guidelines for "environmental footprint" of products and production organizations in May 2013:

- Product Environmental Footprint – PEF and
- Product Environmental Footprint – PEF.

PEF and OEF methods rely on ISO 14040 series in their systematization of ecological balancing [12].

LCA contains an analysis of the product’s entire life cycle, from the obtaining of raw materials for the construction of a new car, to different possibilities for use at the end of life: re-use, recycling, energy use (combustion) and the deposition of debris, including all phases of production, transportation, distribution, use and removal from traffic, Figure 11.

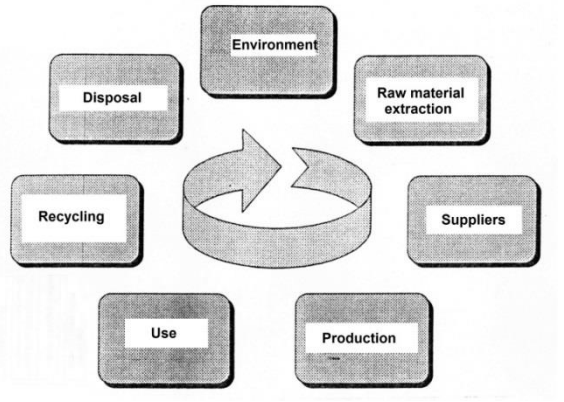

Figure 11. *LCA – circular cycle*

With LCA, the automotive industry has an instrument, which primarily serves for internal optimization, and, through it, for reduction of negative environmental impact during the entire life cycle of the product.

Through ecological auditing, the existing situation in the consumption of materials, energy and creation of waste is compared to the legislation and the necessary activities for the reduction of threats to the environment are pointed out.

About 80% of environmental impact of the product is already predetermined in the development of cars. That is why it is very important, that the LCA and other environmental analyses are involved in development as soon as possible.

The concept of production, selected by the development department, bonds all other participants in the production. Therefore, already in product development, it must be well analysed which environmental impact will the planned production processes have or how the product can be withdrawn from traffic at the end of its use with no negative environmental impact.

The development department, therefore, has a crucial role in terms of environmental protection, because it predetermines subsequent environmental impact of both production processes and products.

In implementation of environmental balance (LCA), ISO 14040 predicts the following steps, Figure 12:

1. defining the objective
2. balancing the used materials and energy (inventory)
3. balancing the environmental impact and
4. assessment the conducted balancing.

The most interesting part in this scheme is the balancing of material and energy (Inventory). All flows of the applied materials and energy consumed are analysed there.

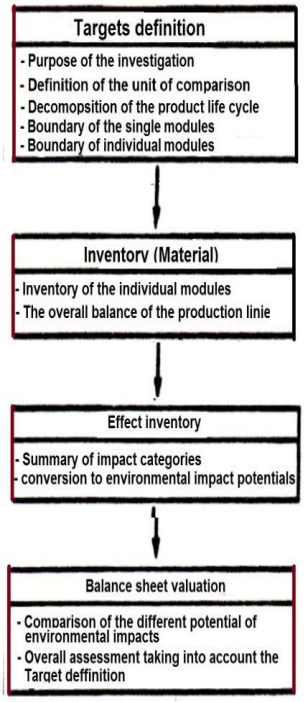

Figure 12. *Process scheme in LCA (ISO 14040)*

The results of this balancing are data regarding the consumption of materials, energy and emission of certain harmful components, Figures 13 and 14.

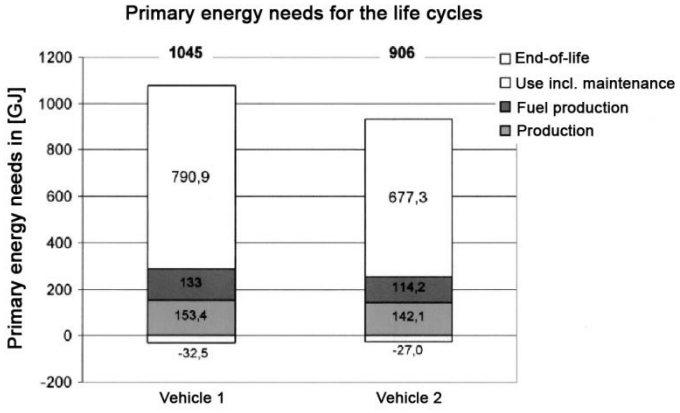

Figure 13. *LCA – Energy consumption of two vehicles*

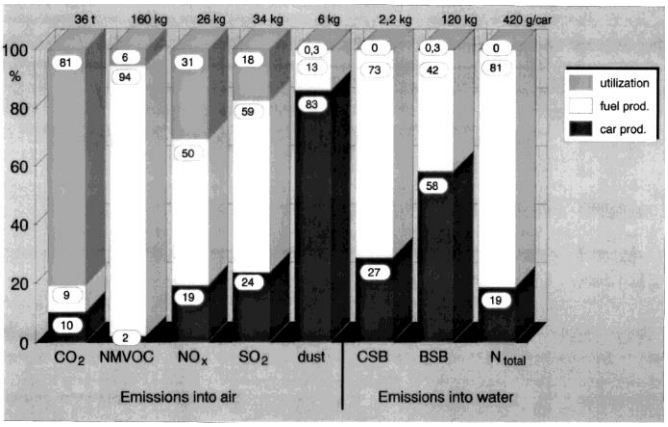

Figure 14. *LCA – Emission of one vehicle (Source: VW)*

A large number of parts in a single car (15,000 to 20,000) make the ecological analysis of each part practically impossible. That is why the LCA is conducted mainly for five key components of the car, which together account for about 90% of the car weight.

Because the depth of production in automotive industry amounts from 30% to 40% of the car weight, the LCA is performed together with the supporting industry, for the most number o Ecological balance is today limited mainly to material balancing (Inventory). Analysis of environmental influence mostly is not done, because there is still not enough reliable data for evaluation of local and temporal impacts of different emissions on the environment.

The guidelines for so-called "Eco-Design" of the vehicles are derived from environmental balancing (LCA):

- designing, taking into account the environmentally clean production and use of vehicles (conservation of the reserves of raw materials and energy, reduction of waste quantities, minimization of energy consumption),
- designing, taking into account the reduction or replacement of hazardous, toxic or otherwise harmful substances from the production or when using cars,
- designing, taking into account the vehicle safety, ease of repair, durability and the ability to upgrade products and
- designing, taking into account the possibilities for re-use and recycling of products.

7. CONCLUSIONS

Modern society's efforts to reduce the negative impact of human activities on nature do not leave aside the end-of-use of the cars. In the European Union, a regulation on old cars was reached, which is mandatory for all Member States of the Union since 2002. Provisions of this regulation request that the re-use of materials must be taken into account already in the phase of designing the new vehicle and they also contain instructions about exploiting the old cars.

The objectives of the European Union can be achieved only if, already at the stage of definition and design of the vehicles, the requirements in terms of recycling are defined. About 20 to 25 years pass from the first definition of the concept, through the start of production, to the recycling of cars. In that period, car producers have to anticipate and take into account the technological development and the development of legal regulations at the time of recycling the cars.

When engineering a car, every part of the vehicle is analysed in terms of ecological criteria: "the possibility of re-use of material", "convenience for recycling" and "critical materials". Recycling of the cars is closely related to the number and type of applied materials and simplicity with which these materials can be identified and separated. The primary principle of "Design for recycling" is to use a closed cycle of materials. Additionally, the recycled material must fully correspond to the new material in all its properties. The safety and quality of the vehicle must not be victims of recycling.

The desired effect of recycling is saving raw materials and energy. Analysis of production of different materials shows that with the increasing application of recycled materials substantial savings in energy consumption and raw materials can be achieved.

In modern cars, the contribution of plastics in car weight is 15%. Selection of these materials plays a very important role when engineering a car taking into account the recycling. Labelling the plastics allows its clean sorting and reusing on a grand scale.

An important criterion for design for recycling of vehicles is easy disassembly of the parts that should be re-used. Car producers are obliged to prepare manuals for disassembly for each vehicle.

The total life of the car encompasses its development, production, exploitation and, at the end of the useful life, the recycling of old vehicles. This system is viewed as a closed cycle. The comprehensive instrument for assessment of environmental impact of the product "from the cradle to the grave" is the ecological balance or Life Cycle Assessment.

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More than 40 years have passed since the first Symposium or Congress "Motor Vehicles & Motors". I had the pleasure and honor to participate in almost all of these events, where I gladly came to give expert reports, but, above all, to meet good comrades and friends from Kragujevac. I thank all previous organizers on regular invitations, but most of all I thank professor Stevan Veinović, because, without his commitment, this, probably record, attendance would not have happened.

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CALIBRATION CERTIFICATION OF VEHICLE WHEEL ALIGNMENT LINE USING PHOTOGRAMMETRY

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ABSTRACT: Security, stability and manageability of vehicle depend largely on the construction of wheels, tires, suspension and steering system. Wheel alignment is part of standard automobile maintenance that consists of adjusting the angles of the wheels so that they are set to the car maker's specification. Calibration certification is performing to check the accuracy of convergence of the vehicle testing/adjusting device on the assembly line. This paper presents the method for measurement of parameters required for calibration certification of vehicle wheel alignment line. Presented methodology can be successfully used for calibration certification of wheel alignment lines both in factories and aftermarket car maintenance. In this way, CMM measurement and certification reference chassis is performed at the measuring place, taking into account the real conditions in which this tool is stored and used. It is very important that this master model is regular, because through it the device and later set all vehicles are adjusted.

KEY WORDS: calibration, certification, wheel alignment, gauge, photogrammetry

KALIBRACIJA UREĐAJA ZA KONVERGENCIJU KORIŠĆENJEM FOTOGRAMETRIJE

REZIME: Sigurnost, stabilnost i upravljivost vozila najviše zavisi od konstrukcije točkova, pneumatika, ogibljenja i sistema za upravljanje. Podešavanje točkova je deo standardne procedure održavanja koji se sastoji od podešavanja uglova točkova, u skladu sa proizvođačkim specifikacijama. Etaloniranje uređaja se sprovodi u cilju provere tačnosti uređaja za testiranje/podešavanje konvergencije vozila na fabričkoj liniji za montažu. U ovom radu predložena je metoda merenja parametara potrebnih za etaloniranje uređaja za podešavanje konvergencije vozila. Prikazana metodologija se može uspešno primeniti za etaloniranje linija za podešavanje točkova u fabrikama, kao i za održavanje tokom eksploatacije. Na ovaj način, uzimaju se u obzir stvarni uslovi pri kojima se ovaj alat čuva i koristi. Veoma je važno da je referentni model tačan, jer se na osnovu njega vrši podešavanje uređaja i kasnije svih vozila.

KLJUČNE REČI: kalibracija, etaloniranje, podešavanje točkova, merilo, fotogrametrija

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CALIBRATION CERTIFICATION OF VEHICLE WHEEL ALIGNMENT LINE USING PHOTOGRAMMETRY

Milan Blagojević [1], Miroslav Živković [2], Saša Jovanović[3]

1. INTRODUCTION

Wheel alignment, sometimes referred to as breaking or tracking, is part of standard automobile maintenance that consists of adjusting the angles of the wheels so that they are set to the car maker's specification [1-3]. The purpose of these adjustments is to reduce tire wear, and to ensure that vehicle travel is straight and true, without "pulling" to one side. New vehicles leave the factory with their alignment checked and adjusted. The adjustment is made by moving the various elements of the suspension and steering system. Properly adjusted suspension geometry allows the rotation of wheels without slipping, blocking and scratching on various types of substrates.

Failure may result in the camber and toe specifications drifting outside the manufacturer's limit. This may lead to vehicle pulling and tire wear. Vehicle pulling causes irritation and/or fatigue while driving the car. Tire wear leads to frequent replacement of tires thus adding to running cost for the consumer.

Alignment angles can also be altered beyond the maker's specifications to obtain a specific handling characteristic. Motorsport and off-road applications may call for angles to be adjusted well beyond "normal" for a variety of reasons.

Gauge calibration determines the deviation from the true value of the indication supplied by a measuring instrument. The results of the calibration process can be used for gauge adjustment. Calibration goes beyond simple adjustment, however. A calibrated gauge can be traced back to a master source. Traceability provides the value added to the calibration process. Gauge calibration represents an important, if not fully appreciated, manufacturing discipline. It should be viewed as an investment. Gauge calibration is the foundation upon which a quality program can be built.

2. MATERIALS AND METHODS

In industry where traditionally CMM are used for certification, we employed optical photogrammetric measuring system. Calibration certification is performed to check the accuracy of convergence of the vehicle testing/adjusting device on the assembly line. Calibration certification is carried out for the following elements of vehicle wheel alignment

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line: convergence device, steering wheel leveller (steering wheel balance master), and reference chassis (rolling master gauge).

2.1. Wheel Alignment Line

Wheel alignment consists of adjusting the angles of the wheels so that they are parallel to each other and perpendicular to the ground, thus maximizing tire life and ensures straight and true tracking along a straight and level road [4]. The primary angles are the basic angle alignment of the wheels relative to each other and to the car body. These adjustments are the camber, caster and toe. On some cars, not all of these can be adjusted on every wheel. These three parameters can be further categorized into front and rear (with no caster on the rear, typically not being steered wheels). The secondary angles include numerous other adjustments, such as: SAI (Steering Axis Inclination), Included angle, Toe out on turns, Maximum Turns, Toe curve change, Track width difference, Wheelbase difference, Front ride height, Rear ride height, Frame angle, Setback. There are even some car models with different factory setting for right and left side wheelbase length, for various design reasons. Changing rims diameter and type of tires will normally not affect the alignment but will affect secondary angles.

The vehicle manufacturers' alignment specifications usually identify a "preferred" angle for camber, caster and toe (with preferred thrust angle always being zero). The manufacturers also provide the acceptable "minimum" and "maximum" angles for each specification. The minimum and maximum camber and caster specifications typically result in a range that remains within plus or minus 1-degree of the preferred angle. If for whatever reason vehicle can't reach within the acceptable range, replacing bent parts or an aftermarket alignment kit will be required.

The reference chassis serves to verify the existing measuring process and to determine the reproducibility and the accuracy of measuring values relating to preset tolerances. The reference chassis is equipped with known characteristics concerning toe and camber values. Each wheel support has different but steady toe and camber values. Reference chassis is manufactured in a way that no mechanical changes in the chassis geometry values can occur within the specified accuracies. Initially, the reference chassis is measured on a 3D measuring machine and delivered with the corresponding measurement report.

Once a month, or in 3 months, or as needed, if the service convergence device is performed or there is doubt as to the settings of the vehicle convergence, it is necessary to set up this master model to the device and check/adjust the convergence device. Corresponding parameters are set in software of the device.

Steering wheel leveller is a mechanical device that is easily attached to the steering wheel at the beginning of the alignment procedure. Steering wheel leveller tool is used to assure a level steering wheel during alignment procedure.

2.2. Photogrammetry

Photogrammetry is a technique of measuring of 3D coordinates. It uses photographs as a metrology medium and triangulation for obtaining 3D coordinates of point’s acquisited on measuring images [5-9].

Photogrammetric measurements are dimensionless, so images contain no information about size of photographed object. If the object with known size is placed in volume that is being photographed, more complete information about geometrical characteristics of measured object is obtained. Photogrammetric measurement requires at least one known length placed in measuring volume. If real coordinates of some reference points are known, their distances can be determined and used for dimensioning of the measured object. The other possibility is using reference points with constant distances, in the form of measuring reference scale bars which are placed in photographed volume (Figure 1).

Distance between reference points is obtained by high precision measuring machines, and scale bars are made of alloys that have a negligible coefficient of linear expansion in certain temperature range. For measurement dimensioning more than one known distance should be used. Length of scale bars should match object dimensions. Every imprecision of reference lengths is then multiplied with ratio between measured object dimension and reference length. For example, if reference measurement 1 meter scale bar is used for measuring object that is 10 meters in length and reference length is manufactured with 0.1 mm error, then the measured object will have 10 times greater error, 1 mm in this case.

If these photographs are taken from at least 2 positions so called "visibility lines" from camera to point on an object can be created, Figure 1. The very precise position of point in space can be determined using mathematical intersection of lines. Photogrammetric measuring devices can measure positions of multiple points simultaneously, while the only limiting factor for the number of points is hardware performance.

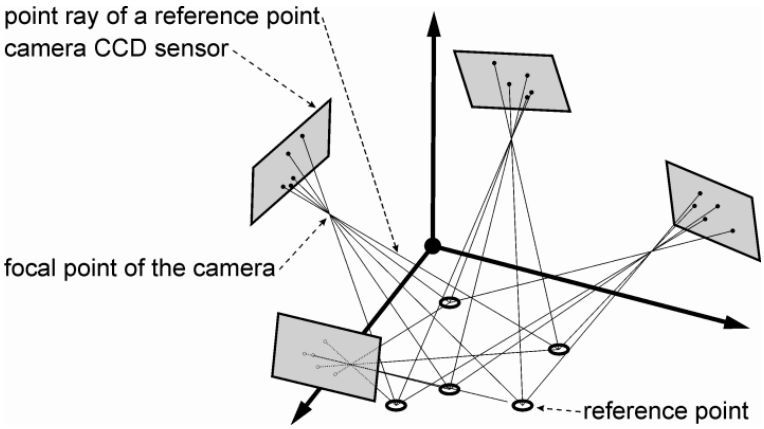


Figure 1. *Basic terms of photogrammetry, relative orientation of measuring images and principle of reference points resection*

Calibration of equipment is required for quality measurement. Calibration is process during which measuring system, with or without a calibration object, performs self-adjustment to ensure accuracy of measurement. Every time optical measuring system TRITOP (Figure 2) is assembled, it has unique and unrepeatable geometric configuration (Table 1). Characteristics of the components of the system are changed over time, and light

conditions are different at different positions of measurement. Possibility of camera to be calibrated as one of the components of the measurement process (making photographs) is called self-calibration. The camera is calibrated during measurement according to the environment variables (temperature, humidity, etc.) that are present during measurement. This is a significant advantage in comparison to the systems that are calibrated in laboratory conditions, since laboratory conditions can be very different than the conditions at measuring location. TRITOP system requires taking 4 starting calibration photographs, from the same position and in the same direction, while rotating the camera by 90 degrees after each photograph.

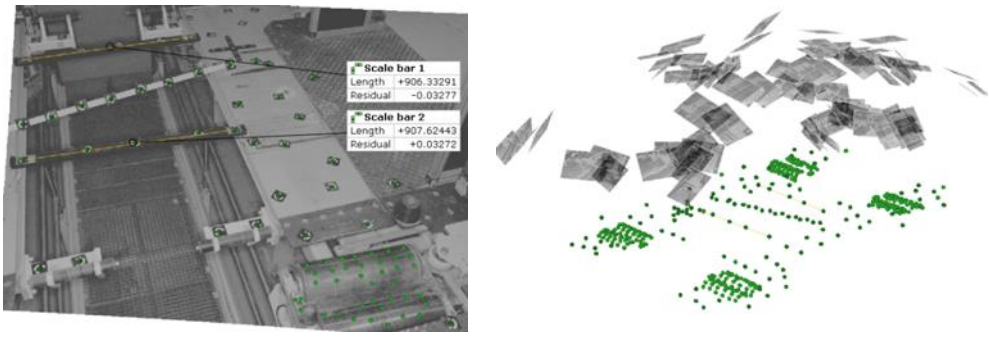
Figure 2. *Measuring equipment and artefacts of optical measuring system TRITOP*

Table 1. *Configuration of optical measuring system TRITOP*

Item	Property
Optical Measuring System	TRITOP
Photogrammetric Camera	NIKON D300s 12.3Mpx
Scale Bars	Optical Scale Bar 1000mm SG00243: Dist.0/1: 906.351mm, CrNi Steel na 20^0C $16.2x10^4K^{-1}$ SG00244: Dist.2/3: 907.577mm, CrNi Steel na 20^0C $16.2x10^4K^{-1}$
Coded Reference Points	15bit Coded Reference Points
Application software	GOM Profesional V7.5 SR2

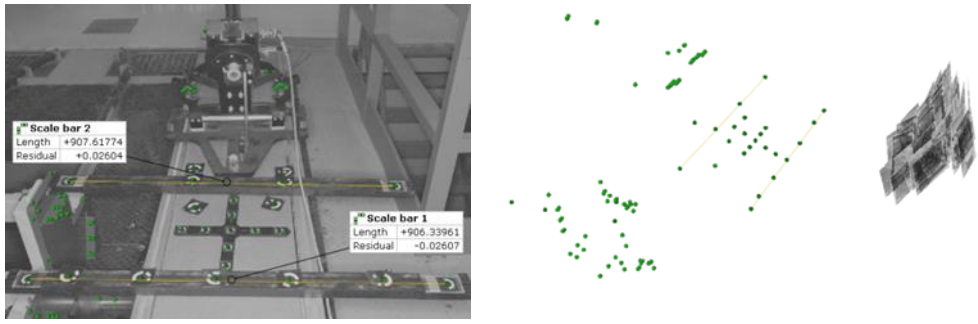
2.3. Measurements

Measuring projects for convergence device, steering wheel leveller, and reference chassis are shown in Figures 3, 4, and 5, respectively.



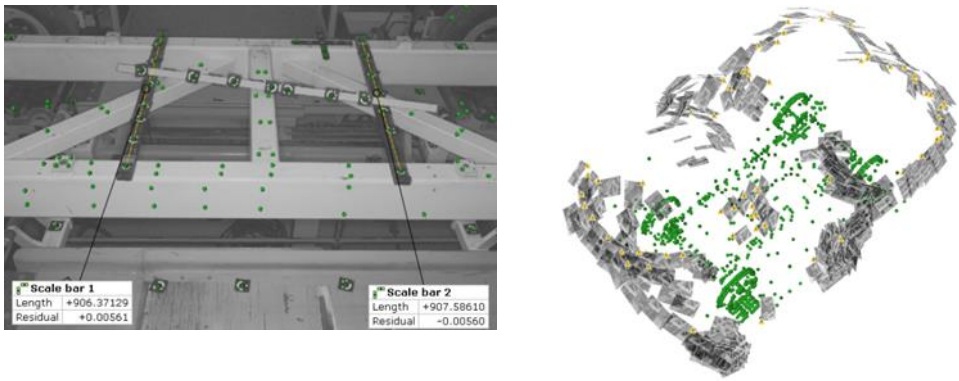
a) *b)*

Figure 3. *Convergence device (non-contact alignment system) measuring project: a) Measuring image, b) Relative orientation of measuring images*



a) *b)*

Figure 4. *Steering wheel leveller measuring project: (a) Measuring image, (b) Relative orientation of measuring images*



a) *b)*

Figure 5. *Reference chassis measuring project: a) Measuring image, b) Relative orientation of measuring images*

During measurement values of air temperature, relative humidity and air pressure were followed. The measured values are shown in Table 2. Appropriate temperature values were entered into the software TRITOP for proper compensation of the temperature influence on the measuring accuracy.

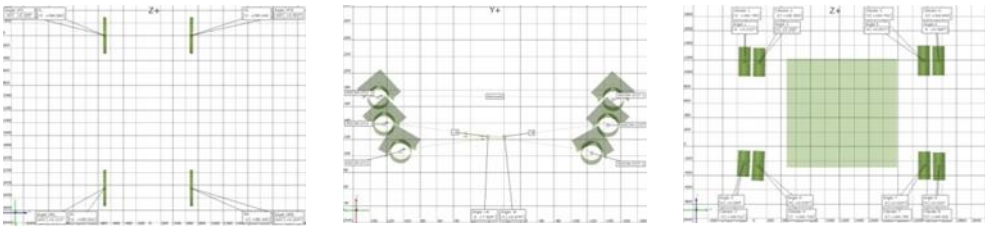
Table 2. *Environmental conditions*

	Convergence device			Reference chassis			Steering wheel leveller		
	from	to	TDM[4]	from	To	TDM[4]	from	to	TDM[4]
Air temp. [°C]	18.7	21.8	± 5	19.7	20.2	± 2	21.1	21.4	± 2
Relative humidity [%]	37.9	40.5	± 30	41.1	41.4	± 10	42.1	42.3	± 10
Air pressure [hPa]	984	984	± 2	994	994	± 2	995	995	± 2

3. RESULTS AND DISCUSION

Geometric entities constructed over uncoded reference points generated in the measuring project are shown in Figure 6. Based on these elements the transformation model in the vehicle coordinate system is carried out and all the necessary measurements.

[4] Tolerance during measurements



a) *b)* *c)*

Figure 6. *Report examples for vehicle wheel alignment line: a) Convergence device, b) Steering wheel leveller, and c) Reference chassis*

3.1. Results for Convergence Device

In order to check whether they are greater than the maximum permissible error (MPE) for a given device, the following measurements were performed for convergence device: level of the rollers (Table 3), height of the rollers (Table 4), diameters of the rollers (Table 5), and angle of the steering wheel balance master (Table 6). Nomenclature of measuring points and rollers of convergence device used in Tables 3-6 is defined in Figure 7.

Maximum permissible error is determined according to manufacturer's tolerances. The measurement results are within the maximum permissible error. The results and uncertainties quoted refer only to the measured value at the time of measurement and carry no implication regarding the long term stability of the instrument.

The reported expanded uncertainty of measurement is stated as the standard uncertainty of measurement multiplied by coverage factor k=2, which for a normal distribution corresponds to a coverage probability of approximately 95%. The standard uncertainty of measurement has been determined in accordance with EA Publication EA-4/02 [10].

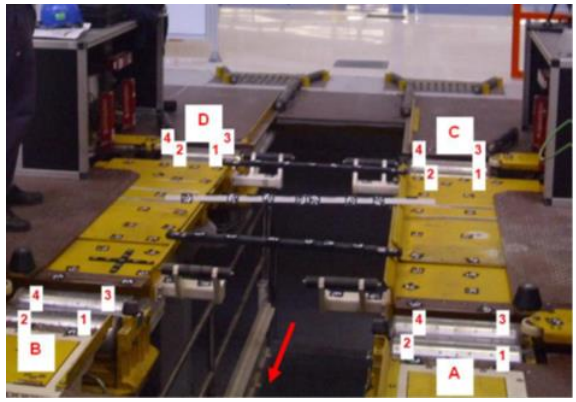


Figure 7. *Nomenclature of measuring points and rollers of convergence device*

Table 3. *Measurement results for rollers level*

Position	Measured value				Uncertainty [mm]
	A [mm]	B [mm]	C [mm]	D [mm]	
1	1544.4	1545.4	1544.3	1545.2	1.2
2	1545.0	1545.0	1544.8	1545.2	1.2
3	1544.2	1545.4	1544.5	1544.8	1.2
4	1544.0	1544.4	1545.2	1544.7	1.2
Reference value	*1545.0*				
Maximum error	1.0	1.0	0.9	0.5	MPE [mm]
Maximum error deviation from reference	1.0	0.6	0.7	0.3	1.0

Table 4. *Measurement results for height*

Position	Measured value				Uncertainty [mm]
	A [mm]	B [mm]	C [mm]	D [mm]	
1 – 2	54.695	54.561	54.822	54.387	0.4
3 - 4	53.740	54.180	54.612	53.870	0.4
Average value	*54.358*				
Error	0.955	0.381	0.210	0.517	MPE [mm]
Max. error deviation from average value	0.618	0.203	0.464	0.488	1.0

Table 5. *Measurement results for rollers diameter*

Position	Measured value				Uncertainty [mm]
	A [mm]	B [mm]	C [mm]	D [mm]	
1 – 2	164.527	164.795	164.784	164.742	0.4
3 - 4	164.720	165.059	164.642	164.694	0.4

Average value	*164.745*				
Error	0.193	0.264	0.142	0.048	MPE [mm]
Max. error deviation from average value	0.218	0.314	0.103	0.051	1.0

Table 6. *Measurement results for reference steering wheel balance master*

Position	Measured value				Uncertainty [°]
	A [°]	B [°]	C [°]	D [°]	
1 – 2	0.040	0.101	0.010	0.051	0.05
3 - 4	0.030	0.106	0.015	0.060	0.05
Average value	*0.052*				
Error	0.010	0.005	0.005	0.009	MPE [°]
Max. error deviation from average value	0.022	0.054	0.042	0.008	0.35

3.2. Results for Steering Wheel Leveller

Measurement results for reference angle at steering wheel balance master (Table 7) shows that error is within the manufacturer's tolerances.

Table 7. *Measurement results for angle in vertical plane*

Position	Measured value [°]	Error [°]	MPE [°]	Uncertainty [°]
+ 8°	7.904	-0.096	0.1	0.01
- 8°	8.079	0.079	0.1	0.01

3.3. Results for Reference Chassis

Height of central point, angle in horizontal plane (toe) and angle in vertical plane (camber) were measured. The measured results are shown in Tables 8-10. All deviations from average values are very small and can be neglected for user.

Table 8. *Measurement results for height*

Position	Measured value				Uncertainty [mm]
	Front Left [mm]	Front Right [mm]	Rear Left [mm]	Rear Right [mm]	
Height of Central Point	585.060	585.444	585.562	585.405	1.2
Average Value	*585.368*				
Maximum error deviation from average value	0.308	0.076	0.194	0.037	

Table 9. *Measurement results for angle in horizontal plane (toe)*

Position	Measured value				Uncertainty [°]
	Front Left [°]	Front Right [°]	Rear Left [°]	Rear Right [°]	
Toe	0.205	0.482	0.111	0.254	0.05
Average Value	*0.263*				
Maximum error deviation from average value	0.058	0.219	0.152	0.009	

Table 10. *Measurement results for angle in vertical plane (camber)*

Position	Measured value				Uncertainty [°]
	Front Left [°]	Front Right [°]	Rear Left [°]	Rear Right [°]	
Camber	90.371	90.571	90.017	90.203	0.05
Average Value	*90.291*				
Maximum error deviation from average value	0.080	0.280	0.274	0.088	

4. CONCLUSIONS

Calibration was performed using photogrammetry measuring system. All values were calculated on the basis of reference objects placed on tyre tread.

The results and uncertainties quoted refer only to the measured value at the time of measurement and carry no implication regarding the long term stability of the instrument [10]. To ensure that gaging and measuring equipment is capable of the job it was intended to do — to measure parts accurately, it must be checked periodically. According to user requirements and their predefined norms, calibration frequency is 1 time per year.

Measurement equipment is calibrated and the reported measurement values are traceable to national standards and thus to internationally supported realizations of the SI-units.

CMM measurement and certification of reference chassis in this way is performed at the measuring place, taking into account the real conditions in which this tool is stored and used. It is very important that this master model is in tolerance, because it is used for setting all parameters for convergence system where all manufactured vehicles are adjusted.

The results are consistent with results obtained the conventional methods of certification. Presented methodology can be successfully used for calibration certification of wheel alignment lines.

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ACOUSTICAL TENSOR AND ELASTIC WAVE PROPAGATION IN ANISOTROPIC MATERIALS USED IN AUTOMOTIVE INDUSTRY

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ABSTRACT: Mechanical behaviour of anisotropic media may be seen the best through its behaviour during bulk wave propagation. Such waves may be decomposed into finite plane waves propagating along arbitrary direction ***n*** in solid. Properties of these waves are determined by dependence between propagation direction and constitutive properties of media. Three types of such waves may be distinguished in connection to three displacement vectors, which determine acoustic polarization. The most of dynamical systems are naturally nonlinear; here we are going to write Reimann-Christoffel equation. This equation represents propagation condition of bulk waves as set of three homogeneous linear equations. Materials used in present analysis are fibre reinforced with one or two families of continuous fibres. Often used represent of such materials is epoxy resin carbon fibres composite whose material constants are determined with ultrasound methods.

KEY WORDS: mechanical behaviour, anisotropic media, shape functions, composite materials, bulk waves

AKUSTIČNI TENZOR I ELASTIČNA PROPAGACIJA TALASA U ANIZOTROPNIM MATERIJALIMA KORIŠĆENIM U AUTOMOBILSKOJ INDUSTRIJI

REZIME: Mehaničko ponašanje anizotropnih medijuma najbolje se vidi kroz njegovo ponašanje tokom širenja masivnog talasa. Takvi talasi se mogu razgraditi u konačne ravne talase koji će se prostirati duž proizvoljnog ***n*** pravca u solidu. Svojstva ovih talasa određena su zavisnošću pravca širenja i konstitutivnih svojstava medijuma. Tri tipa takvih talasa se mogu razlikovati u odnosu na tri vektora pomeranja, koja određuju akustičnu polarizaciju. Većina dinamičkih sistema su prirodno nelinearni; ovde ćemo pisati Reimann-Christoffel jednačinu. Ova jednačina predstavlja uslov propagacije masivnih talasa kao skup tri homogene linearne jednačine. Materijali koji se koriste u sadašnjoj analizi su ojačani vlaknom sa jednom ili dve porodice kontinualnih vlakana. Često korišćeni predstavnik takvih materijala je kompozit vlakno eposkidne smole čije su konstante materijala određena ultražvučnim metodoma.

KLJUČNE REČI: mehaničko ponašanje, anizotropni medijum, funkcija oblika, kompozitni materijali, masivni talasi

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ACOUSTICAL TENSOR AND ELASTIC WAVE PROPAGATION IN ANISOTROPIC MATERIALS USED IN AUTOMOTIVE INDUSTRY

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1. INTRODUCTION

New products have been introduced in order to replace materials such as metal and cement. One such material is fibre-reinforced composite, which are have been competing with materials such as steel, aluminium and concrete in cars, aircraft, buildings and everyday sports goods. Materials as these materials due to combining high strength and stiffness with low weight and have many advantages concerning the cost, dimension, surface properties, thermal properties, electric properties, etc. They are also cheaper because they reduce the cost as their maintenance costs are very low, besides a lot of work is being done in order to make them more environmental friendly.

The most important aspect of fibre-reinforced materials is their mechanical behaviour. Constitutive relations has been made by Spencer, for extensible fibres in [1,2] and for inextensible fibres in [3]. These relations are coordinate free, which enabled us to study the material concentrating to the unit vector field tangent to preferred direction, called fibre. Here we are concerned fibre-reinforced composites which have an important property of being anisotropic, and in many cases this anisotropy may be very strong, in the sense that mechanical properties are strongly depend on the direction. The main futures of these materials are the improvement of stiffness and strength, reduction of wear and creep, anisotropic properties, improved strength in fibre direction, high price and complex manufacturing techniques.

In this paper, we consider the propagation of bulk waves in elastic solids reinforced by two families of strong mechanically equivalent fibres.

2. LOCALIZATION FORM AND ACOUSTIC TENSOR

Most dynamical systems are naturally non-linear and it is not easy to find closed solution of such systems. In this paper we are mainly interested in illustrating that, mathematically and we consider infinite domains so that we can omit questions concerned with the nature and interpretation of the correct boundary conditions, as well as the appropriate form of the stress tensor and the associated tractions. Equation describing the

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initial weak discontinuity, assuming that tangent stiffness tensor on both sides of the surface of discontinuity, has the same value and the following form

$$c_{ijkl} n_j n_l p_k = 0, \tag{1}$$

where

$$c_{ijkl} = \frac{\partial W}{\partial e_{ij} \partial e_{kl}}, \tag{2}$$

represents the tangent stiffness tensor, the unit normal to singular surface and represents the polarisation vector. The second order tensor, called the localization tensor is

$$\Gamma_{ik} = c_{ijkl} n_j n_l. \tag{3}$$

This tensor is singular and the polarisation vector is eigenvector associated with the eigenvalue zero, while the classical localization condition in the considered case may be expressed in form

$$\det(\Gamma_{ik}) = \left| c_{ijkl} n_j n_l \right| = 0. \tag{4}$$

A material model shall be used here for which the localization tensor is non-singular and, in the analysis of wave propagation, termed as the acoustic tensor, is symmetric and positive definite leading to three positive eigenvalues. The equation of motion may be expressed for infinitesimal displacements u_i in the form

$$\sigma_{ij,j} + f_i = \rho \ddot{u}_i. \tag{5}$$

If strains are small enough, equations are linear and relation connecting stress and strain are generalized Hooke's Law given as

$$\sigma_{iji} = c_{ijkl} e_{kl}, \tag{6}$$

which is postulated by Cauchy. This law is base of linear elasticity. Coefficients are stiffness coefficients. These equations may be solved for the monochromatic wave motion if the harmonic plane wave displacement is expressed as follows

$$u_k = A p_k \exp(ik(n_r x_r - vt)). \tag{7}$$

In equation (7) is the amplitude factor, while is the unit polarization vector, is the imaginary unit, k is the wave number, the wave normal and is the phase velocity. Equations (6) and (7) lead to Riemann-Christoffel's equation

$$(c_{ijkl} n_j n_l - \rho v^2 \delta_{ik}) p_k = 0. \tag{8}$$

Due to the symmetries of the stiffness tensor, the matrix expression in the brackets on the left-hand side is also symmetric. This implies that the three eigenvalues obtained for

applying the condition for nontrivial solution of the set of homogeneous equations, will be real. The system of homogeneous equations (8) has nontrivial solution provided that

$$\left|\Gamma_{ik}-\rho v^2\delta_{ik}\right|=0\ ,\ \left|\Lambda_{ik}-v^2\delta_{ik}\right|=0\ ,\ \Lambda_{ik}=\Gamma_{ik}/\rho=c_{ijkl}n_jn_l/\rho=\lambda_{ijkl}n_jn_l \tag{9}$$

Equation (9) in matrix form is

$$\begin{vmatrix}\Lambda_{11}-v^2 & \Lambda_{12} & \Lambda_{13}\\ \Lambda_{12} & \Lambda_{22}-v^2 & \Lambda_{23}\\ \Lambda_{13} & \Lambda_{23} & \Lambda_{33}-v^2\end{vmatrix}=0, \tag{10}$$

The components of Riemann-Christoffel's tensor may be expressed as

$$\begin{aligned}\Gamma_{il}=c_{ijkl}n_kn_j=c_{i11l}n_1n_1+\left(c_{i12l}+c_{i21l}\right)n_1n_2+\left(c_{i13l}+c_{i31l}\right)n_1n_3\\ +c_{i22l}n_2n_2+\left(c_{i23l}+c_{i32l}\right)n_1n_3+c_{i33l}n_3n_3\,.\end{aligned} \tag{11}$$

3. MATERIALS REINFORCED BY ONE FAMILY OF FIBRES

These materials possess transversal isotropy and, without loss of generality, one may choose one of Cartesian axis, to coincide with fibre direction, for example unit vector of fibre direction may be written as $(a_i)=(1,0,0)$. Such material is usually treated in coordinate system with one axes coincides with axes of transversal isotropy and study constrains on strain energy function from requirements that stay invariant during rotations around that axes. Here we are going to use coordinate free constitutive equations following Spencer [1]. The most general quadratic form of strain energy function, with elastic constants: λ, μ_T, μ_L, α, β, is given as

$$W=\frac{1}{2}\lambda(tr\,\boldsymbol{\varepsilon})^2+\mu_T tr\,\boldsymbol{\varepsilon}^2+\alpha(\boldsymbol{a}\cdot\boldsymbol{\varepsilon}\cdot\boldsymbol{a})tr\,\boldsymbol{\varepsilon}+2(\mu_L-\mu_T)\boldsymbol{a}\cdot\boldsymbol{\varepsilon}^2\cdot\boldsymbol{a}+\frac{1}{2}\beta(\boldsymbol{a}\cdot\boldsymbol{\varepsilon}\cdot\boldsymbol{a})^2 \tag{12}$$

Stiffness tensor then may be calculated as follows

$$\begin{aligned}&C_{ijkl}=\frac{\partial^2 W}{\partial\varepsilon_{ij}\partial\varepsilon_{ij}}=\lambda\delta_{ij}\delta_{kl}+\mu_T\left(\delta_{ik}\delta_{jl}+\delta_{jk}\delta_{il}\right)+\\ &\left(\mu_L-\mu_T\right)\left(a_ia_k\delta_{jl}+a_ia_l\delta_{jk}+a_ja_k\delta_{il}+a_ja_l\delta_{ik}\right)+\\ &\alpha\left(a_ka_l\delta_{ij}+a_ia_j\delta_{kl}\right)+\beta a_ia_ja_ka_l.\end{aligned} \tag{13}$$

In expression (13) material constant μ_L represents shear modulus along the fibre direction a_i, μ_T represents shear modulus perpendicular to the fibre direction. Remained material

constants λ, α, β may be connected to other modulus such as extension modulus, Yung's modulus or Poisson ratio.

Components of acoustic tensor may be expressed as

$$\begin{aligned}
\rho\Lambda_{11} &= \left(\lambda + 2\alpha + \beta + 4\mu_L - 2\mu_T\right)n_1^2 + \mu_L n_2^2 + \mu_L n_3^2, \\
\rho\Lambda_{12} &= \left(\lambda + \alpha + \mu_L\right)n_1 n_2, \\
\rho\Lambda_{13} &= \left(\lambda + \alpha + \mu_L\right)n_1 n_3, \\
\rho\Lambda_{22} &= \mu_L n_1^2 + \left(\lambda + 2\mu_T\right)n_2^2 + \mu_T n_3^2, \\
\rho\Lambda_{23} &= \left(\lambda + \mu_T\right)n_2 n_3, \\
\rho\Lambda_{33} &= \mu_L n_1^2 + \mu_T n_2^2 + \left(\lambda + 2\mu_T\right)n_3^2.
\end{aligned} \tag{14}$$

3.1 Numerical analysis of slowness surfaces when fibres become very strong

The materials used in the present analysis are fibre reinforced with one family of continuous fibres. Since fibres are much stronger than the matrix, anisotropic properties are emphasized. If a stiffness tensor is defined then, for an arbitrary propagation direction, the phase velocities may be calculated for all three waves, one of which is quasi-longitudinal and the remaining two are quasi-transversal. Their reciprocities represent the points of the corresponding slowness surfaces and for calculating them is useful to define the sagittal plane, presented in Figs. 1. Material constants for such materials, which density is given as $\rho = 1{,}60 \cdot 10^3 kg/m^3$, are measured by ultrasound methods and reported in [4], are

$$\begin{aligned}
&\lambda = 5{,}65 \cdot 10^9 Nm^{-2}, \quad \mu_T = 2{,}46 \cdot 10^9 Nm^{-2}, \quad \mu_L = 5{,}66 \cdot 10^9 Nm^{-2}, \\
&\alpha = -1{,}28 \cdot 10^9 Nm^{-2}, \quad \beta = 220{,}90 \cdot 10^9 Nm^{-2}.
\end{aligned} \tag{15}$$

Let us choose Cartesian system whose axes coincide with axes of material symmetries, and we may imagine vertical plane, which coincide initially with coordinate plane and rotate around vertical axis for arbitrary angle.

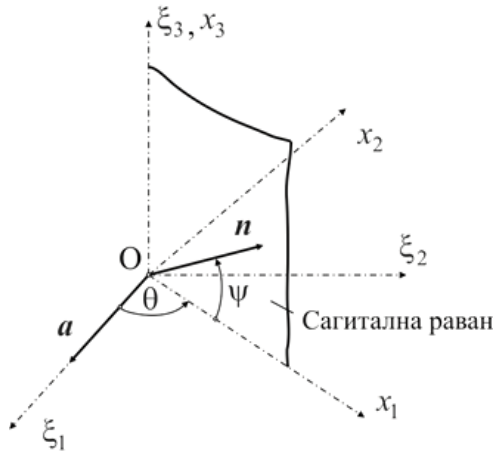

Figure 1. *One family of fibres*

Taking into account that the material constant given in equation (15), for material reinforced by one family of fibres, slowness surfaces are calculated in program pack MATLAB and presented in Figures 2 and 3.

By varying angle between 0 and 2π may be calculated slowness curve in sagittal plane whereas by rotating of sagittal plane around axes for angle slowness surface may be completed. Slowness surfaces, for material reinforced by one family of fibres, are calculated in program pack MATLAB and presented in Figures 2 and 3, for angle. In these figures quasi-longitudinal waves are represented with solid lines, whereas quasi-transversal waves are represented with broken lines.

When fibres become stronger, such a behaviour is more emphasized showing that in the inextensibility case one quasi-shear phase velocity degenerates and may propagate in exceptional directions only. The innermost slowness curve, associated to quasi-longitudinal waves, tends to degenerate to a point, as shown in Figure 3, indicating an infinite phase velocity when the material becomes subject to the inextensibility constraint. The direction of energy propagation, which is normal to the slowness surface, in such cases indicates a singular behaviour of the energy flux vector in a constraint limit.

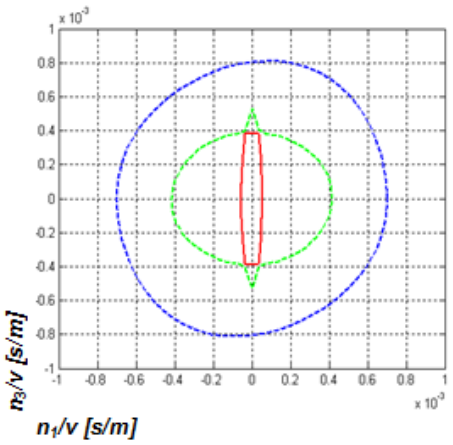

Figure 2. *One family of fibres*
$\theta = 60°,\ \beta = 220{,}29 \cdot 10^{10}\ N/m^2$

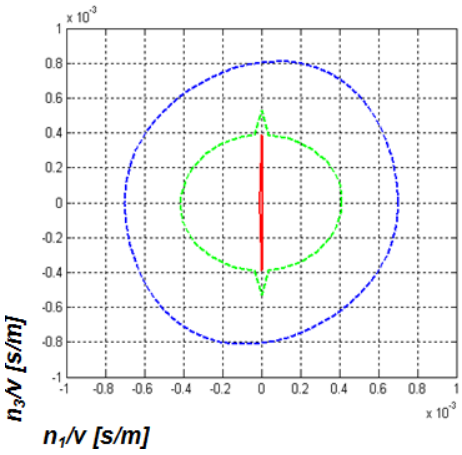

Figure 3. *One family of fibres*
$\theta = 60°,\ \beta = 220{,}29 \cdot 10^{12}\ N/m^2$

7. CONCLUSIONS

Mechanics of continuum treats material on macroscopic level in which microscopic level may be used as preparation for homogenization purposes; anisotropy has different effects on wave propagation as well as on complete elastic behaviour of media, which may be observed trough fact, that wave front deviate from spherical shape. About anisotropic material behaviour, general conclusions in mechanical sense are taken from considering of bulk waves propagation.

For considered material acoustic tensor, as propagation condition, has been formed, and determined for different directions of wave propagation. For particular material reinforced by one family of fibres components of that tensor are calculated. These calculations has practical significance, because it has been formed easy mathematical approach which may give fast answer about material behaviour in dynamic circumstances, which often appear in parts of motor vehicles.

This approach may be used as first approximation of dynamical behaviour of real parts with anisotropic characteristics that appears very often in consideration of vehicle construction parts.

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