

International virtual journal
for science, technics and
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MACHINES
TECHNOLOGIES
MATERIALS

YEAR VIII **Issue 2 / 2014** **ISSN 1313-0226**



Published by
Scientific technical
Union of Mechanical Engineering



MACHINES, TECHNOLOGIES, MATERIALS

INTERNATIONAL VIRTUAL JOURNAL

PUBLISHER

SCIENTIFIC TECHNICAL UNION OF MECHANICAL ENGINEERING

108, Rakovski Str., 1000 Sofia, Bulgaria

tel. (+359 2) 987 72 90,

tel./fax (+359 2) 986 22 40,

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www.mech-ing.com/journal

ISSN 1313-0226

YEAR VIII ISSUE 2 / 2014

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THE MOST IMPORTANT MACEDONIAN FOUNDRY COMPANIES

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Abstract: In this paper short review about the most important Macedonian foundry companies is given. During preparation of this work authors visited production units of the foundry companies and discussed with their management about the most important things concerning their current work and the plans for the future. It was found that six of the companies are the most important for Macedonian industry. All of them are private companies. They are founded before transition period, and their production is mainly intended for the foreign market. It is important to say that they have very ambitious plans for improvement of technological processes and increase of production.

REVIEW OF MACEDONIAN FOUNDRY COMPANIES



MZT LARNICA AD :: Skopje

MZT Larnica A.D. Skopje is Stakeholder Company in private ownership. During its existence MZT Larnica A.D. Skopje has experienced several significant investments and transformations. In 1945 - MZT Larnica is founded as department in composite of MZT Tito. In 1970 - Significant reconstruction with new furnaces and Gisak semiautomatic moulding lines is performed in the foundry. From 1976 - MZT Larnica grows in independent legal subject. In 2006 new melting aggregates are installed, and was agreed and is in phase of realization new automatic moulding line as encircled technological manifold with new sand plant and shot blasting machine. Company manufacture castings from gray, ductile iron (90%) and nonferrous metals with fully encircled technological line; starting from manufacturing pattern equipment, core making, moulding, pouring, shot blasting, machining, coating, packing, and warehousing in own store for selling.

MZT Larnica A.D. Skopje has qualified labour force which is in system of continuous education for performing of following tasks: Manufacturing of pattern foundry equipment from wood, plastics and metal;

Manufacturing of cores with CO₂ procedure and shell procedure; Moulding on lines:

- 800x800x300 - automatic line SAVELI
- 1000x800x300x500; 1200x1000x300x500; 1600x1200x300x500; line KINKEL WAGNER.

Own plant for epoxy coating.

Own plant for classic painting.

Own plant for machining, lapping, milling, and shave.

Company poses 2 medium frequency induction furnaces with capacity of 5t/hour.

Own laboratory for mechanical testing, metallographic testing, testing of sand quality as well and chemical analyses of metal.

Chemical analyses of metal.

The most important products in MZT Larnica are: parts for machine industry, fittings (with flanges and pipes, with tyton junction, for plastic pipes, with flanges mobile and pipes for plastic pipes with flange mobile), decorative products, air valves and hydrants, sewage armour and parts by agreement. Some of their products are given in figure 1.

MZT Larnica A.D. pays special attention to the quality of the products fully respecting request of the customers, taking in mind satisfaction with product and business cooperation. In company say that development is their imperative, through which they secure competitiveness on market and company profitability, with inclusion of employees in the development of the same according their knowledge, experience.

Company in its working is fully oriented at continuous respect of customer requests and their satisfaction, continuous development which secures competitive product and company profitability including employees in company development according their competence, knowledge, training and experience. Choosing respective suppliers is additional guarantee for product quality.

Company offer various types of cooperation as follows: manufacturing of tools for pouring and castings, castings with your tool, machining, coating, transportation, etc.

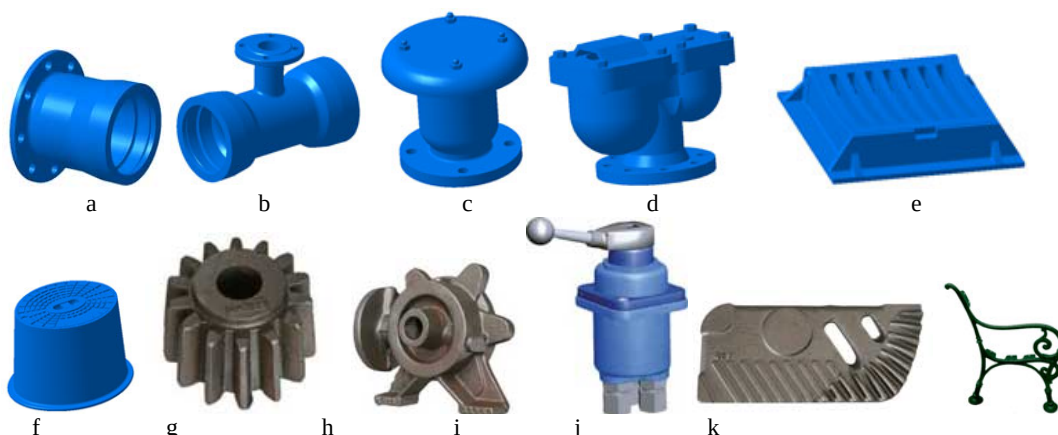


Figure 1 a. EU flanged and tyton socket pieces, b. MMA flange on tyton tee, c. VV air valve - single body, d. DVV automatic air valve with two balls, e. sewage greed and frame, f. pit hydrant cover - with eliptic opening, g. sprocket h. bearing case, i. direct brake, j. segment for steam boiler, k. bench side



ALUMINUM AND ZINC FOUNDRY

The aluminum and Zinc Foundry LLC – Resen produces high quality aluminum and zinc effluences by using a technology of high pressure casting. The company follows the production program of the factory producing heating items – Algreta, and also introduced new types of radiators that suit the worldwide quality standards and which can be used in the world's largest heating systems, as is the example in Moscow and throughout Russia and Macedonia.

The factory is equipped with Italian machinery used for pressure foundry, heating chamber machines ranging from 20 to 180 t used for zinc casting effluences and cold chamber machines ranging from 180 to 1100 t also used for casting aluminium effluences. The metal melting is central but mostly the work is according to the wishes of the clients, with more types of aluminium alloys. Estimated number of employees is 74.

There is a special part in our Foundry equipped with a machinery park used for producing and processing of radiator parts where all of the radiator parts are cut, welded, examined and assembled.

The manufacturing process goes on without releasing the waste waters and other materials into the environment. The water is remanufactured inside the factory compound where it's used again as clean technological water.

In the factory there is a paint shop section where the radiators are being painted with an electrostatic white paint RAL 9016.

Main products of the company besides three types of radiators are: hydraulics and pneumatics parts, automobile industry parts, electro industry parts, and miscellaneous parts (figure 2).

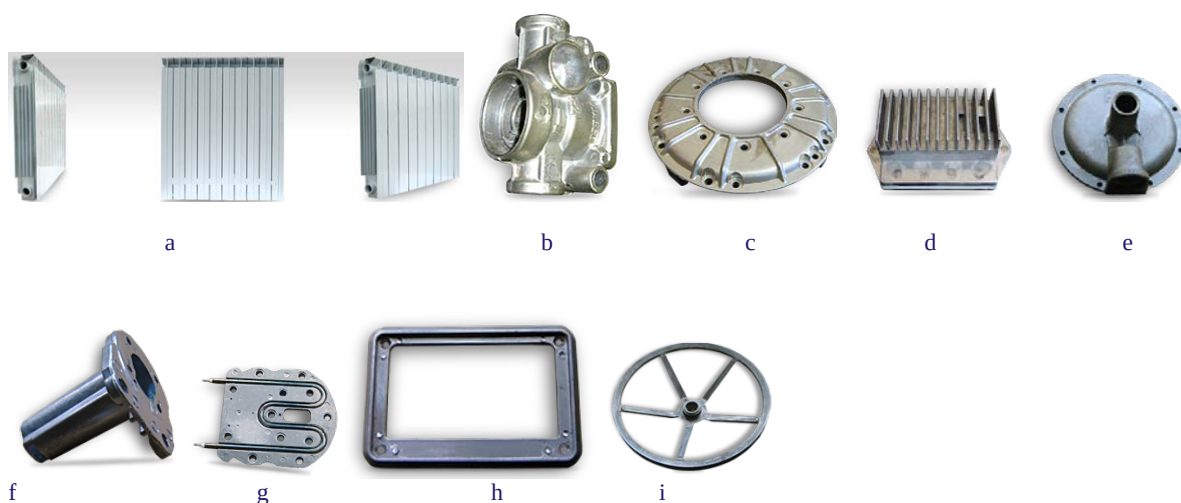


Figure 2 Different casting in Aluminum and Zinc Foundry LLC a. radiator, b and c. hydraulics and pneumatics parts, d and e. automobile industry parts, f and g. electro industry parts, h and i. miscellaneous parts.



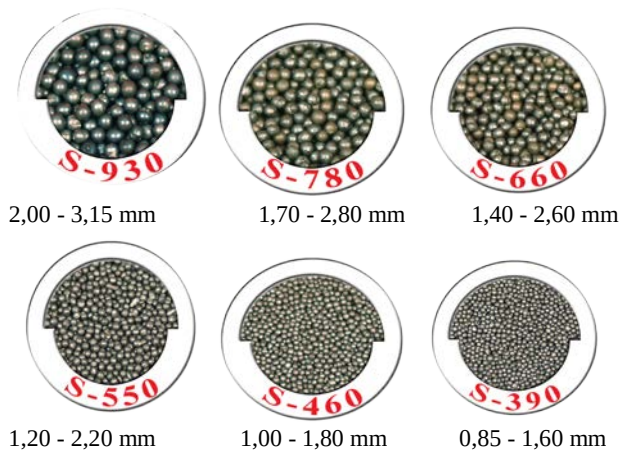
ZELEZNIK AD - MACEDONIA

Zeleznik AD is a private share holders company for production and trade founded in 1970. Since its first products sold in the neighboring countries, today in more than 90% of Zeleznik production is export oriented. Company supply its long term business partners located in the countries of the European Union and also in the overseas countries.

Zeleznik AD is a company from the field of ferrous metallurgy which deals with production 1. Low carbon steel shots;

2. Various kinds of steel castings.

As can be seen from the figure 3 steel shots have different granulation, from 0,18 mm until 3,15 mm. Packing of steel shots is in 25 kg polypropilen bags on pallet of one tone.



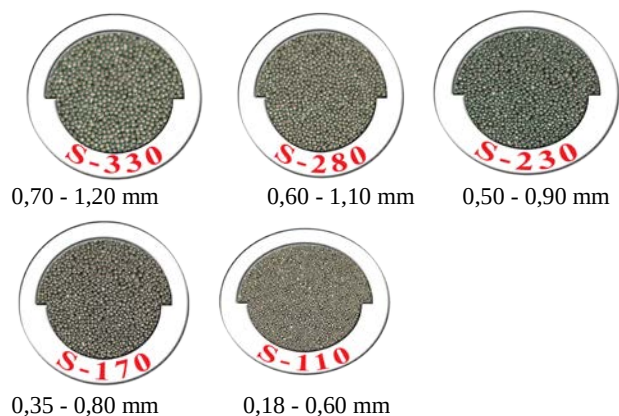


Figure 3 Different granulation of steel shots produced in Zeleznik AD

Some technical dates about steel shots are given below:

Chemical composition: C = approx. 0,10% - 0,15%, Si = approx. 0,10% - 0,15%, Mn = approx. 0,50% - 1,00%, P = max. 0,035%, S = max. 0,035%;

Period of durability: ERVIN TEST K50 = 2000 - 2500 cycles;

Hardness: HRc = 41 - 45; HV = 420 - 480;

Specific weight: 7,5kg/dm³;

Filling weight: 4,4kg/dm³;

Microstructure: Bainite / Martensite.

The most usual application of steel shot is given in the table 1.

Table 1. Application of steel shots in different sectors.

GENERAL APPLICATIONS		
PRODUCTION	PRODUCTS	PURPOSES
FOUNDRY	Iron and Steel Casting Product	Desanding
	Non-Ferrous Casting Products	Deburring
STEEL WORKS & ROLLING MILL	Blooms and Billets	Descaling
	Hot and Cold Rolled Products	
METALWORKING	Drawn and Extruded Products	Shot Peening
	Steel Tubes	
MISCELLANEOUS	Metal Construction & Shipbuilding	Reconditioning
	Forging, Stamping, die-work	
	Spring, gears, sundiers	
	Drums, Wagons, Site Equipment	
	Graphite Electrodes	
	Heavy Concrete	
	Stone Dressing	

As can be seen from the figure 4 (a-c) different castings are produced in AD Zeleznik. These parts are mainly produced from manganese steel and are mainly used in three industry areas: quarries, steam power plants and building and construction.

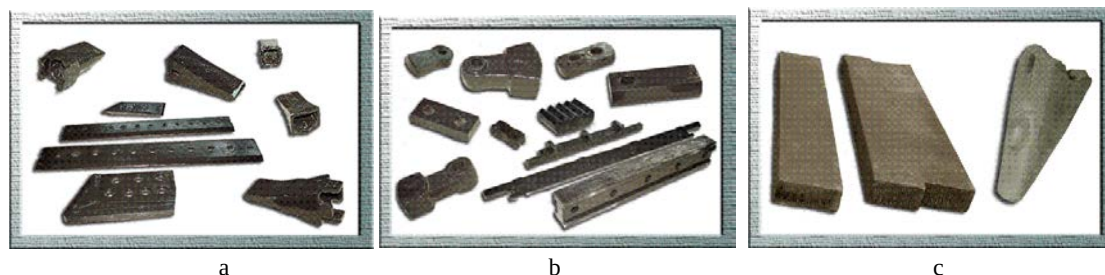


Figure 4. Castings from Zeleznik AD for different industry sectors: a. quarry b. building and construction c. steam power plants.

For production of steel shots and castings, company posses three electro inductive furnmnces (2 tones each). Two of them are low frequency (500Hz) and one is medium frequency furnace (50 HZ). Maximal annual production is 2000 t castings and 8000 tone steel shots.



RZ Institute was formed and built in parallel with the foundation of RZ "Skopje". Its concept followed the needs of the former steelworks factory and wider. The institute started with its work in 1967. On December 05, 1997 the Institut undergone the process of transformation into the privately-owned establishment. Since February 2001, RZ Institute is fully private-owned facility. After privatisation of RZ Institut AD Skopje, the need of the economic efficiency arise, which led to the necessary improvements of the market competitive abilities. These were the reasons for the rehabilitation, modernisation, and re-assignment of the existent

technological lines and production processes. RZ Institut AD Skopje employs 56 permanent employees.

Nowadays RZ Institut is a shareholding company with the dominant activity of production of alloys from coloured metals (aluminium and copper) and non-metals. RZ Institute offers production of coloured metallurgy, metallurgy in production of the fire proof materials, as well as the production of industrial lime.

RZ Institute produce different types of Al alloys according EN standards (table 2) and desoxidation module, used in steel industry (table 3). Other alloys can be produced on the customers' demands.

Table 2 Aluminium alloys according EN standa produced in RZ Institut

aluminium alloys	Si	Fe	Cu	Mn	Mg	Zn	Cr	Ni	Pb	Sn	Ti	each	total
DIN225 EN AC-45000	5.0-7.0	1.0	3.0-5.0	0.2-0.65	0.55	2.0	0.15	0.35	0.3	0.15	0.2	0.05	0.35
DIN226 EN AC-46000	8.0-11.0	0.6-1.2	2.0-4.0	0.55	0.55	1.2	0.15	0.55	0.35	0.25	0.2	0.05	0.25
DIN230 EN AC-44300	10.5-13.5	0.45-1.0	0.1	0.55	0.55	0.1	/	/	/	/	0.2	0.05	0.25
DIN231 EN AC-47100	10.5-13.5	0.6-1.2	0.7-1.2	0.55	0.35	0.55	0.1	0.3	0.2	0.1	0.2	0.05	0.25
DIN233 EN AC-43200	9.0-11.0	0.65	0.35	0.55	0.2-0.45	0.35	/	0.15	0.1	/	0.2	0.05	0.15
DIN239 EN AC-43400	9.0-11.0	0.45-1.0	0.1	0.55	0.2-0.5	0.15	0.05	0.15	0.15	0.05	0.2	0.05	0.15

Table 3 Desoxidation module, used in steel industry

Element	Si	Fe	Cu	Zn	Pb	C	S	P
%	1-4	1-3	0.6-2	0.2	0.2	>0.1	>0.1	0.01

Mould and sand castings of aluminium is implemented in RZ Institut too. Mould casting is used for obtaining of ingots with dimensions 640x75x65, weight between 5.5 and 6.5 kg, packed on cast palletes from the same material, with dimensions 640x640x700, and weight between 600 and 650kg. Different forms on the customers demand (unique pieces or small series) are produced too. Casting in sand moulds is implemented for different single forms or small series (elements for sewerage and water systems, industrial systems: underground hydrants, ventile heads, fire hydrants, pipes and so on.

Production of copper alloys according to EN standards is performed too. The following copper alloys are mostly produced (according to EN standards): Rg-bronzes, tin-lead bronzes, tin bronzes and aluminum bronzes.

Casting of copper alloys implies mould casting of ingots with dimensions 640x75x65, weight between 13 and 15kg. Different

forms on the customers' demand (unique pieces or small series are produced too. Sand Moulds is performed for casting of cylinders from D=20 mm to D=200 mm and pipes from D=20 mm to D=200 mm. Different prophiles on customers' demands are produced too.

Casting of art sculptures out of bronze, brass and aluminium is implemented in current time. RZ Institute has an adequate equipment and trained personnel for creating art sculptures starting from vax model and finishing with casting in bronze, brass or aluminium.

Two aggregates are used for melting of aluminium (1,2 and 0,5 t) and two for melting of copper alloys (both of 0,5 t). All of them are heated by natural gas. Agregates for aluminium can be seen in the figure 5. One small inductive furnace (11 kg) is used for decorative casting.



Figure 5 Agregates for melting aluminium alloys ina RZ Institut



J.S.A. TEAL - Tetovo

J.S.A. TEAL - Tetovo was established in 1978 as a part of ALUMINA from Skopje. About ten years later in accordance with the Enterprise Law, in 1989, TEAL was registered as an independent company which became a Holding Company in 1991. In 1999, the German company RAKU from Obernburg - Germany became the dominant owner of TEAL possessing 53% of it. - Since 1978, TEAL is a company which satisfied the buyers needs for quality aluminium profiles. The mission of the Company is to overcome the expecting the clients and to become "Supplier of high quality aluminium profiles of hard and soft aluminium alloys". TEAL is export - oriented company. Over 90 % of the products are for the foreign markets like Serbia, Germany, Austria and Slovenia. The annual manufacturing capacity is about 2000 tons of final product, in three shifts.



Figure 6 Aluminium logs

The main activity of the holding company J.S.A. TEAL from Tetovo is the production of aluminium alloys and profiles. More concretely:

- Production of aluminium logs, blocks for deoxydation and alloys
- Production of pressed aluminium profiles, pipes, bars and construction profiles;

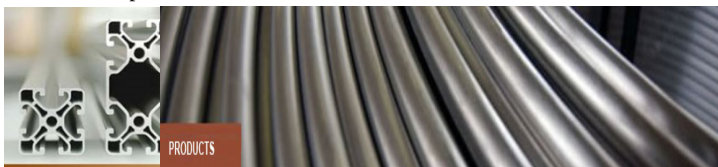


Figure 7 Final products in J.S.A. TEAL

The improvements in the foundry, where the melting and the foundering of the aluminium is done, are planned with the inclusion of the SNIF system (Spinning Nozzle Inert Flotation System). This is a refinement system which allows a better quality of the metal, reduced time of processing, reduced emissions and lower operation costs.

The inclusion of surface protection is an extra given value to the final product, and the same will be done through the use of the process of anodization, and later on through the initiation of a process for surface protection with dust painting.

Key production groups are:

The manufacturing process, implemented in TEAL, is actually an integrated manufacturing system, which starts with aluminium and some other elements like copper, silicon and magnesium. Aluminium as raw material in the manufacturing process is with the pureness of 99.7 % - 99,8%. The process ends with a final product - aluminium profile in different circle dimensions and shapes. Melting of raw material is in two electro inductive furnaces (5,5 t each).

It means that the manufacturing process is divided into two main phases:

- Process of manufacturing aluminium alloys in shapes of logs and ingots, figure 6;
- Extrusion of logs into profiles with different circle dimension (figure 7), followed by heat treatment where necessary.

- Production of aluminium gallantry, aluminium brackets for electrical distribution network and similar products;
- Key production groups are: aluminium alloys in a shape of logs and ingots and aluminium profiles in different circle dimension. These products are later on used in the automobile industry, construction, airplane industry, machine industry and etc.



- Aluminium alloys in a shape of logs and ingots.
- Aluminium profiles in different circle dimension.

These products are later on used in the automobile industry, construction, airplane industry, machine industry and etc. The company also manufactures all kind of products made of aluminium profiles, like doors and windows and also products for industrial purposes, including aluminium brackets for electrical distribution network.

The most important categories in J.S.A. TEAL - Tetovo are: aluminium logs, blocs for deoxydation, aluminium alloys, aluminium profiles, pipes and bars and aluminium gallantry.



LTH Castings* LTH Learnica-Ohrid

LTH Learnica in Macedonia was founded in 1961 and joined the LTH Castings Group as the last member in 2005. Starting in the 60s as a supplier for the ex Yugoslav car industry, covering various part and material categories the company evolved to a structured and cost-efficient die-casting producer, based on the technical knowledge with favourable labour cost.

LTH Learnica is specialized for complex, high-quality high-pressure die-aluminium components and systems. Supplier of both high-tech and less complex parts manufactured by a network that is

spread across Central and South Europe (Slovenia, Croatia and Macedonia).

Highest-quality, innovative solutions and dedicated customer service under continuous improvement.

Core competences of the company are: die-casting of aluminium parts, tool design and manufacturing, processing of aluminium alloys:

- EN AC 46000 (AlSi9Cu3, Al226)
- EN AC 44300 (AlSi12, Al230)

- EN AC 47100 (AlSi12Cu, Al231)

Additional Service is heat treatment of aluminium parts.

The recently introduced in-house tool and mould production supports the LTH Castings Group tool demand and enables on the other hand the site to focus on manufacturing aluminium anti-vibration components, spools as well as some non-automotive electronic housing components. The site focuses on raw part production, labour intensive products and products with intensive and sensitive mould maintenance demand.

Core competences of the company are:

- Aluminium die-cast automotive components;
- In-house manufacturing of tools and devices;
- Development of products, tools and processes;

- One stop shop - from initial development to serial production;

- Simultaneous and resident engineering.

Strategic focus of the company is: quality first approach, Volume production with fully exploiting the labour cost advantages, focusing rough part with grinding, tapping and drilling possibilities, increasing share of parts demanding intensive tool maintenance, further development of tool shop, SE Europe proximity advantages (Romania, Turkey etc.), specialisation to selected product groups.

Key products of the LTH Learnica is: tool-making; die-cast tools, deburring tools sleeves.

Series production includes: anti vibration components safety systems castings (spools).

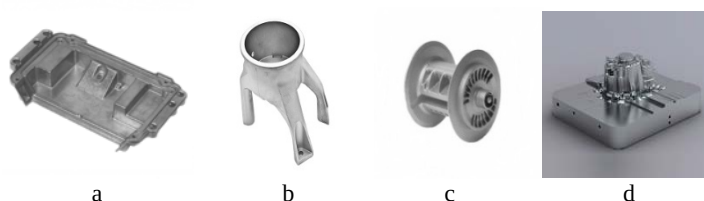


Figure 8 LTH Learnica products a. automobile part, b. anti vibration component, c. spool, d. tool making

There is four aggregates (furnaces) heated by natural for melting of aluminium alloys, figure 9. Fifteen casting machines are used for die casting of aluminium alloys in LTH Learnica.



Figure 9 Pouring of molten metal from the melting furnace, LTH Learnica

CONCLUSION

In this paper an overview of Macedonian foundry companies is given. In current time six companies play key role in Macedonian economy. All of them were separately presented. These companies were founded in the period of socialist society. They past very hard period of transition. Nowadays they are private companies with domestic or foreign owners. They have similar planes for the future to improve technological process, to employ high-quality personel (production and control), to increase production, to acquire new markets and to protect environment.

LITERATURE

- MZT Learnica A.D. Skopje, Makedonija , <http://learnica.com.mk>
 Aluminium and zink foundry Resen,makedonija
<http://www.learnica-resen.com.mk>
 Zeleznik A.D. Demir Hisar, Makedonija,
<http://www.zeleznik.com.mk>
 RZ Institut AD Skopje Makedonija www.rzinstitut.com.mk
 A.D. Teal Tetovo, Makedonija, <http://www.teal.mk>
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CURRENT STATE AND PERSPECTIVES OF INCREASING OF TRIBOTECHNICAL CHARACTERISTICS OF ZINC ALLOYS

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Abstract: *Cast zinc alloys are widely used in various industries of national economics, including the manufacturing of products for tribotechnical applications. There are such approaches to solving the problem of improving the tribotechnical characteristics of zinc alloys, as the search for new alloy compositions and optimization of existing ones. However, the capabilities of traditional alloys to achieve the desired properties of products that meet the growing demands almost exhausted at present time. One of the most effective ways to improve the tribotechnical properties of zinc alloys is realization of the principle of reinforced heterophase structure, which is the basis of creation of composite alloys.*

KEYWORDS: ZINC ALLOYS, COMPOSITE ALLOYS, TRIBOTECHNICAL CHARACTERISTICS, INTERMETALLIC REINFORCEMENT, LIQUID-PHASE TECHNOLOGY

1. Introduction

Actuality of improving of the operational reliability of machines and mechanisms in mechanical engineering is constantly increasing. The decision of this problem largely associated with providing of effective long-term operation of friction units.

Cast zinc alloys are widely used in various industries, including the manufacturing of products for tribotechnical applications. Many of modern zinc alloys are being actively developed abroad, already surpass analogues on copper and aluminum base on bearing capacity, wear resistance and other tribotechnical characteristics. Furthermore, an important feature of zinc alloys is possibility of its use for manufacturing of products with high requirements on corrosion and damping properties.

Works in the direction of further improving of the antifriction properties of zinc alloys will substantially increase volumes of their application in various branches of engineering.

2. Modern approaches to increasing of tribotechnical characteristics of zinc alloys

Standard zinc alloys of TsAM type (Zn-Al-Cu system) response to the main requirements imposed to materials for products for friction units, in particular, wear resistance in the given operating conditions, low friction coefficient, good and fast conformability, ability to resist scuffing and seizing, and also high physical-mechanical properties at working temperatures [1]. Good tribotechnical properties of such alloys are caused by their heterogeneous structure which depends on a ratio and amounts of aluminum and copper and can consist from primary superfluous α -phases solid solution of zinc and copper in aluminum, β -phase – almost pure zinc, η -phase – solid solution of aluminum and copper in zinc and ϵ -phase – chemical compound CuZn_3 [2].

At the same time, it should be noted that the capabilities of traditional alloys to achieve the desired properties of products that meet the growing demands by now almost exhausted. Aware of such approaches to solving the problem of improving the tribotechnical characteristics of zinc alloys, as the search for new alloy compositions and optimization of existing ones. Examples are the works of Russian scientists to increase the aluminum content in the zinc alloy (pat. USSR № 65621), adding up to 6.5% tin in alloys of TsAM type (pat. USSR № 61307), etc.

Another trend in the direction of improving of the quality and reliability of castings for tribotechnical purposes is improving of manufacturing processes of tribotechnical materials, including advanced technologies of melting and out-furnace processing, casting, heat treatment and thermochemical treatment of castings.

It is known that with decreasing of grain size in castings increased not only the mechanical properties but also the tribotechnical characteristics. To improve the dispersion structure of cast billets, reliability and durability of their work is actively being developed and introduced into production special casting techniques

with intense heatsink (gravity and centrifugal casting in water-cooled molds, casting and freezing of the others). Structure refinement of zinc alloys may also be due to treatment with a modifying additives of Ti up to 0.2 % or by external physical influence on the melt.

As the practice shows, a significant increase in the tribotechnical characteristics of zinc alloys is possible during heat treatment. In [3] it is shown that the homogenizing annealing of castings from ZA27 alloy at a temperature of 370°C with an exposure within three hours and the subsequent quenching in water can reduce the wear rate under load of 100 N to 46% compared to the as-cast alloy.

One of the most effective ways to improve the tribotechnical properties of zinc alloys is the realization of the principle of reinforced heterophase structure, which is the basis of creation of composite alloys. In this context, the problem of developing of compositions and manufacturing processes of production of zinc composite alloys in recent years has attracted increasing attention of researchers. As a matrix for producing of such alloys the greatest application have zinc alloy ZA27, containing 25-28% Al. As the reinforcing components were successfully tested particles of SiC, Al_2O_3 and graphite [4, 5]. In the paper [6] in the molten zinc alloy ZA27 at 500°C was stirred titanium dioxide particles of 30-50 micron fraction in an amount from 2 to 6%. An increase in tensile strength up to 20%, hardness up to 10% for the composition of ZA27 + 6% TiO_2 is noted.

In [7] tribotechnical characteristics of composite alloy of ZA27 + 2..13% Si are studied. Low solubility of silicon in zinc in a solid state leads to separation of particles of primary silicon in the process of crystallization. Non-linear dependence of wear resistance of an alloy on the content of silicon is established. In the range from 2% to 5% of Si wear resistance lowering with further increasing from 5% to 13% of Si is watched. Such behavior of an alloy represents special interest and requires additional investigations.

2. Zinc composite alloys reinforced with intermetallic phases

A significant advantage of zinc as a matrix for composite alloys in comparison with other metals is technological effectiveness in processes of liquid-phase combination with a reinforcing phase and at production of cast products. In particular, zinc alloys have high fluidity, low shrinkage, low tendency to formation of cracks and porosity in castings. Practice shows that at smelting of zinc alloys is achieved reduction of energetic expenses by 25-50% as compared to aluminum alloys and 75% as compared with bronze. Significant advantages of zinc composites compared to conventional alloys and analogs are enhanced tribotechnical characteristics in combination with good damping and anticorrosive properties, processability during the production of cast products and the subsequent machining.

Insufficient level of elaboration of the problem of producing and research of zinc composite alloys is connected with substantial

technological difficulties arising due to poor wettability of reinforcing phase by matrix melt. Wettability is a necessary condition for the formation of strong adhesive bonds at the interfaces and determines the potential possibility of producing of composite alloy. There are different approaches to solving this problem: applying of metallophilic coatings on the particles, alloying of the matrix alloy with surface-active components, ultrasonic impact on the melt, methods of endogenous reinforcing, etc. The most appropriate method is the method of endogenous reinforcing provides of the formation of new reinforcing phases directly into the predetermined composition matrix melt during producing of the composite alloy that provides single-stage and more economical process. Such composite alloys possess the highest level of adhesive bonds at the interfaces due to the close lattice matching of contacting phases, thermal stability, better distribution and dispersion of endogenous reinforcement. The method is relatively simple, multi-operated and doesn't require of special equipment. At the same time, special importance is represented by the question of selection of such initial components of the reinforcing complex which would provide active course of reactions of synthesis of given phase components at the producing of zinc composite alloys by liquid-phase methods.

Currently, the authors conducted investigations on the development of new compositions of metal matrix composite alloys based on zinc. Preliminary experimental studies showed fundamental possibility of obtaining zinc composite alloys reinforced intermetallic phases. Used relatively simple in from the point of view of realization of technological process method of entering of the dispersed phase in the molten zinc, based on the use of high-concentrated ligatures. As matrix alloy used standard alloy TsAM 10-5 GOST 21437-95. The choice of alloy is caused by its wide application for the production of antifriction products and sufficiently high aluminum content, allowing using of the principle of intermetallic reinforcing. For formation of given reinforcing phases in the matrix melt used titanium powder, which is added to the Al-Cu ligature at the stage of its production. The received triple master alloy Al-Cu-Ti entered in a molten zinc of Ts0 mark ($>99.975\%$ Zn) at $480 \pm 10^\circ\text{C}$, heated until complete dissolution and was poured in a metal mold.

Application of the described technique allowed to receive zinc composite alloys with different content of titanium, for example ZnAl10Cu5 alloy + 1,5 wt. Ti %. Structure of this alloy is shown on Fig. 1 and consists of a cast matrix with uniformly distributed particles of different form and sizes. As a whole, the received alloy has a heterogeneous structure with a clear phase boundary and the dense adhesive bond between the matrix and the reinforcing intermetallic phases.

Hardness is one of the most important characteristics that determine the bearing capacity of the composite alloy, as well as in a large extent the temperature ranges of friction units. Results of hardness measurements of alloys ZnAl10Cu5 + 1,5 wt.% Ti show its increase from 90 MPa (matrix alloy) to 130-135 MPa. The hardness of samples of composite alloys of different compositions shown in Fig. 2.

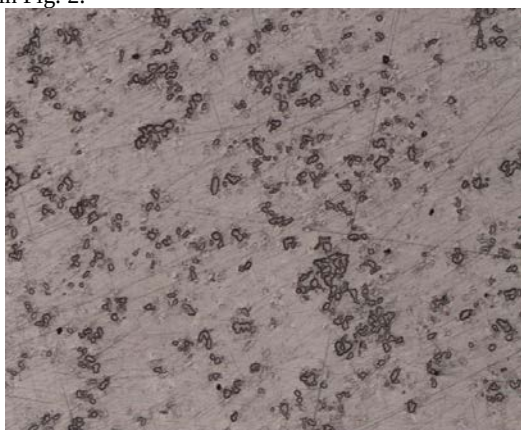


Fig. 1. Structure of alloy ZnAl10Cu5 + 1,5 wt.% Ti ($\times 50$)

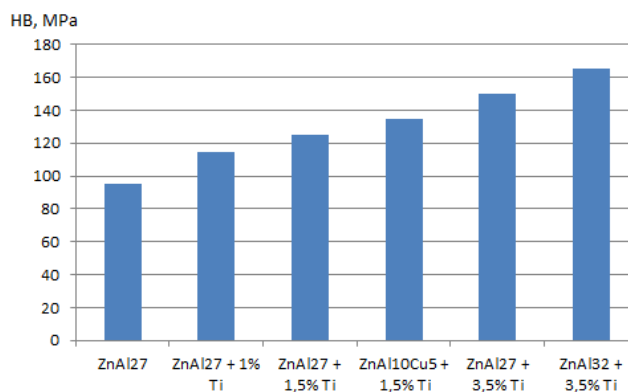


Fig. 2. Hardness of as-cast zinc composite alloys

3. Conclusion

The analysis shows that at present time considerable attention is paid to a problem of increasing of tribotechnical characteristics of zinc alloys. Results obtained at pilot experimental investigations on synthesis and study of zinc composite alloys reinforced with intermetallic phases shows perspectives of use of these alloys for manufacturing of responsible details for mechanical engineering working in the conditions of intensive wear.

4. Literature

- [1] Marukovich E.I., Karpenko M.I. Wear-Resistant Alloys. – M.: Mechanical Engineering, 2005. – 428 p.
- [2] Zharkov V.Ya. Triboengineering Material Science. – Bryansk, BSTU, 2005. – 159 p.
- [3] Babic M. et al. Influence of Heat Treatment on Tribological Behavior of Zn-Al Alloys // Tribology in Industry. – Vol. 29, Iss. 1&2. – 2007. – p. 23-31.
- [4] Bobic B., Babic M., Mitrovic S. et al. Microstructure and Mechanical Properties of Zn25Al3Cu Based Composites with Large Al_2O_3 Particles at Room and Elevated Temperature // Int. J. Mat. Res. 101 (2010) 12. pp. 1-8.
- [5] Mitrovic S., Babic M., Stojanovic B. et al. Tribological Potencial of Hybrid Composites Based on Zinc and Aluminium Alloys Reinforced With SiC and Graphite Particles // Proc. of 12th International Conference on Tribology. – Kragujevac, Serbia, 2011. – p. 138-145.
- [6] Ranganath G., Sharma S.C., Krishna M. et al. A Study of Mechanical Properties and Fractography of ZA-27/Titanium-Dioxide Metal Matrix Composites // Journal of Materials Engineering and Performance. – 2002. – Vol. 11(4). – pp. 408-413.
- [7] C. Tijun, Y. Chengren, F. Mingfeng et al. Friction and Wear Properties of Casting In-situ Silicon Particle Reinforced ZA27 Composites // China Foundry. – Vol.6, No.1. – 2009. – p. 1-8.

FINITE ELEMENT SIMULATION OF THIN-WALLED BEAM TYPE- STRUCTURE BUCKLING UNDER CREEP REGIME

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Abstract: This paper presents creep buckling finite element modeling of steel beam-type structure. For beams under sustained loads the loss of stability may occur during a period of exploitation of structure even for loads lower than critical buckling load. For that reason stability is characterized by critical buckling time instead the critical buckling load. The simulation is performed using four noded Kirchhoff-Love theory based shell finite elements. For a space frame, as the test example, critical buckling times are calculated for different levels of applied load, temperature conditions and steel chemical composition.

Keywords: FINITE ELEMENT, THINN-WALLED BEAM, BUCKLING, CREEP, FRAME, STABILITY

1. Introduction

In the field of structural engineering beams and frames constitute a very important class of load-carrying components, where they are applied both in their stand-alone forms and as stiffeners for some plate or shell structures. An important consideration concerns the accurate prediction of their limit load-carrying capacity. Because such structures, especially those of thin-walled cross-sections, could display very complex structural behavior which comprises both geometric and material inelasticity, it has been a major activity of many structural engineering researchers in the recent years [1].

Columns under sustained loads are generally unstable in the regime of creep. That means that loss of stability may occur during a period of exploitation of structure even for loads lower than critical buckling load. Due to that reason stability is characterized by critical buckling time defined as load duration for which buckling deflections become infinitive [2]. Contrary to the linear stability analysis which is able to determine a creep buckling load for which the buckling deformation tends to infinite during the infinite time, the non-linear theory shows that the creep buckling can occur at a finite time, at which buckling deformation tends to infinity for any load less than the critical buckling load determined in elastic cases. The non-linear response of a load-carrying structure should be solved using numerical methods, e.g. the finite element method, and some of incremental descriptions.

Shell elements are especially useful when the behavior of large structures is of interest. The flat shell elements are the simplest ones due to their low computational cost, so such elements are very popular. Contrary to Mindlin-Reissner type, Kirchhoff-Love type based shell elements neglect transverse shear deformation [3].

In this paper a beam finite element model is used to evaluate the critical buckling loads of the frame as eigenvalues. Afterwards, for geometrically and materially nonlinear creep buckling analysis shell finite element model is used.

2. Modelling of Creep

In the case of small strains the additive decomposition of the total strain tensor into an elastic part and an irreversible creep part is postulated. The constitutive equation is the following [4, 5]:

$${}^2S_{ij} = \frac{E}{1+\nu} ({}^2\varepsilon_{ij}'' - \Delta\varepsilon_{ij}^c), \quad (1)$$

where ${}^2S_{ij}$ and ${}^2\varepsilon_{ij}'$ are deviatoric parts of stress and strain tensors in current unknown configuration, ${}^2\varepsilon_{ij}'' = {}^2\varepsilon_{ij}' - {}^1\varepsilon_{ij}^c$ while ε_{ij}^c denotes creep deformation tensor.

Creep deformation increment can be calculated as:

$$\Delta\varepsilon_{ij}^c = {}^1k {}^1S_{ij}, \quad (2)$$

where factor 1k is:

$${}^1k = \frac{3}{2} \frac{{}^1\bar{\varepsilon}^c}{\bar{\sigma}} \Delta t, \quad (3)$$

with $\bar{\varepsilon}^c$ and $\bar{\sigma}$ as effective creep strain rate and effective stress.

Time increment Δt represents the real time passed during the element movement from last known configuration to current unknown configuration, so it is: $\Delta t = {}^2t - {}^1t$.

Effective creep strain rate $\bar{\varepsilon}^c$ from equation (3) can be obtained according to some mathematical creep model eg. Norton power creep law as:

$$\bar{\varepsilon}^c = K \bar{\sigma}^n, \quad (4)$$

where K and n are Norton material constants.

3. Numerical example

Fig. 1 shows a one-storey space frame loaded by vertical force of intensity F at point B. The junction at B was performed in a manner to prevent warping of the beam members at the joint, as shown in detail of figure.

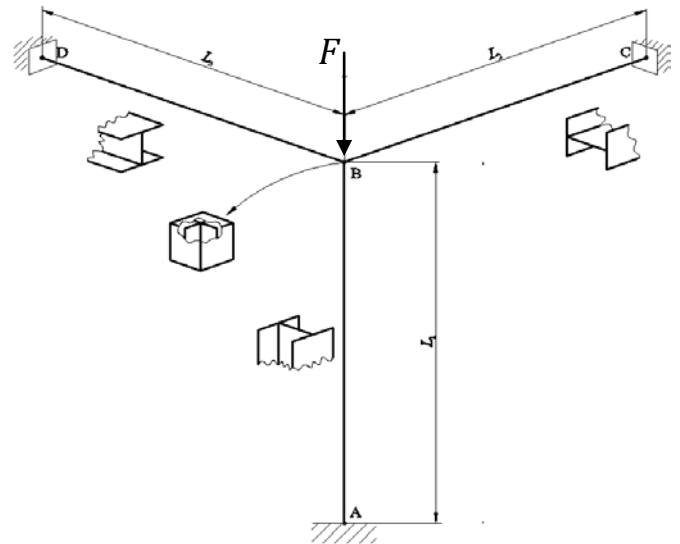


Fig. 1 Space frame

The material moduli are: elastic modulus $E = 210$ GPa and shear modulus $G = 80.77$ GPa; the Poisson ratio is $\nu = 0.3$. The length of beam members are $L_1 = 4100$ mm, $L_2 = 3100$ mm and $L_3 = 3100$ mm. The boundary conditions of beam members are defined as clamped at points A, C and D while at the junction point, as it is

already mentioned, the warping degrees of freedom are supposed to be restrained.

All frame members are made of European wide flange HEB profiles, with the following dimensions: flange width $b = 100$ mm, web height $h = 100$ mm, flange thickness $t_f = 6$ mm and the web thickness $t_w = 10$ mm, (see Fig. 2).

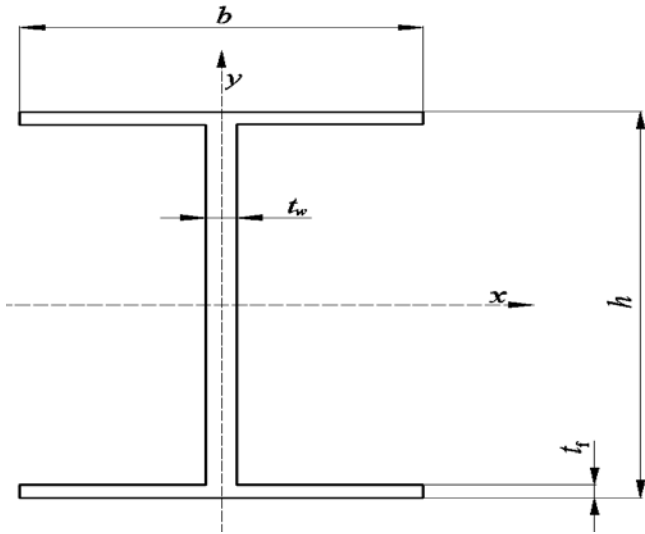


Fig. 2 HEB beam members cross-section

Three different finite element models are made. A shell finite element model with 4928 8-noded finite elements are made in computer software FEMAP.

The first deformation mode for space frame under consideration is shown on Fig. 3. This mode belongs to the group of so called sway buckling mods.

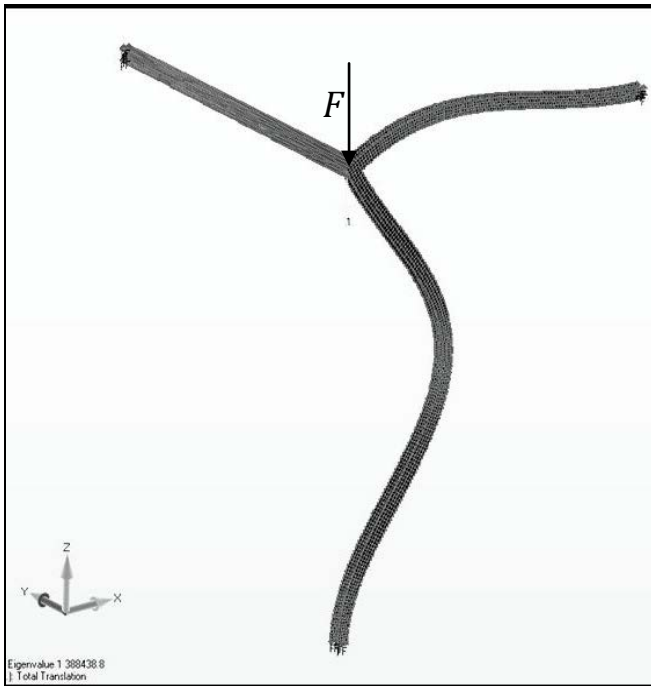


Fig. 3 The first deformation mode for space frame

To obtain critical buckling load, the analyses in an eigenvalue manner are also performed by beam MASTAN2 computer solver. This is important as the first step of simulation in order to determinate the static critical buckling load value. The buckling loads obtained from the above mentioned models are listed in Table 1. The number of finite elements used in both models is given for convenience.

Table 1: Critical buckling loads and the number of finite elements used for space frame for different finite element models

FE model	No. of elements	Buckling load [N]
MASTAN2 (beam)	3	381880
FEMAP (shell)	4928	388439

For a creep buckling analysis, the frame is loaded with three different constant forces:

$$F_1 = 0.85 F_{cr} = 330173 \text{ N}$$

$$F_2 = 0.80 F_{cr} = 310751 \text{ N}$$

$$F_3 = 0.75 F_{cr} = 291329 \text{ N}$$

A perturbation forces of $0.001F$ intensity, is applied at the middle point of vertical column in the positive X -direction to initiate the deformation shape due to the inquirements of the non-linear buckling numerical modelling.

Two different chemical composition carbon steels are used and for the first carbon steel two different temperatures are used. Norton power creep law is adopted with following constants [6, 7]:

- material A - carbon steel (0.15 C, 0.50 Mn, 0.23 Si) at 538°C:
 $n = 3.05, K = 0.12 \cdot 10^{-13} [10 \text{ mm}^2/\text{N}]^n \cdot \text{h}^{-1}$;
- material A - carbon steel (0.15 C, 0.50 Mn, 0.23 Si) at 649°C:
 $n = 2.85, K = 0.16 \cdot 10^{-10} [10 \text{ mm}^2/\text{N}]^n \cdot \text{h}^{-1}$;
- material B - carbon steel (0.43 C, 0.68 Mn, 0.20 Si) at 649°C:
 $n = 1.7, K = 0.12 \cdot 10^{-8} [10 \text{ mm}^2/\text{N}]^n \cdot \text{h}^{-1}$.

Fig. 4 shows X -direction translational displacement of perturbation load point versus creep time for material A at constant temperatures levels of 538°C for applied load levels of $0.85F_{cr}$, $0.8F_{cr}$ and $0.75F_{cr}$. It should be pointed that all three values are smaller than the previously determinate critical buckling load.

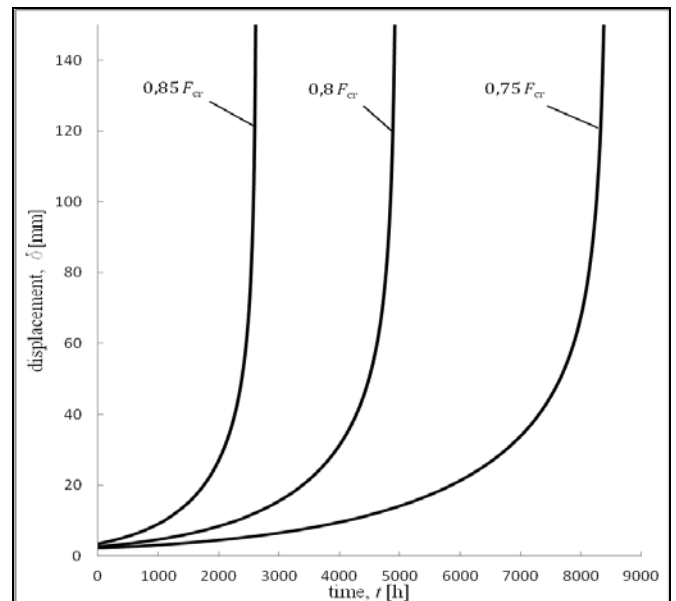


Fig. 4 Creep buckling curves for material A at 538°C

The Fig. 5 presents the creep buckling curves for material A at temperature of 649°C. The Fig. 6 show the diagram of buckling curves in the same manner but in this case for material B at constant temperature level of 649°C.

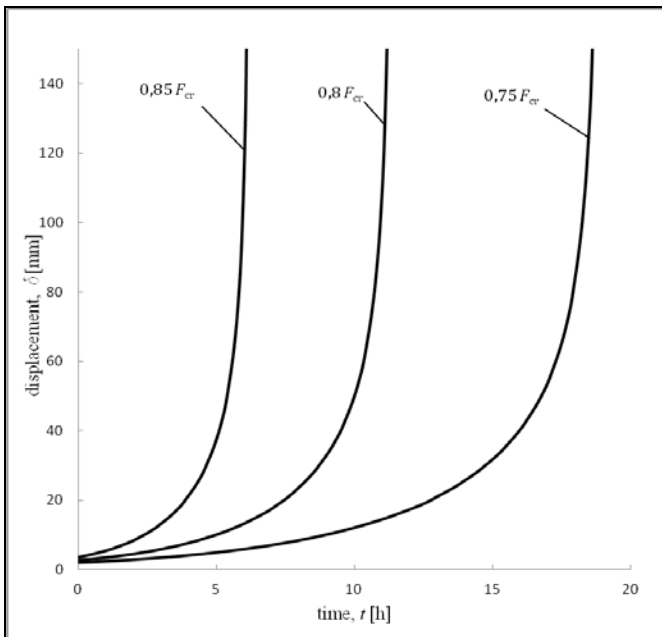


Fig. 5 Creep buckling curves for material A at 649°C

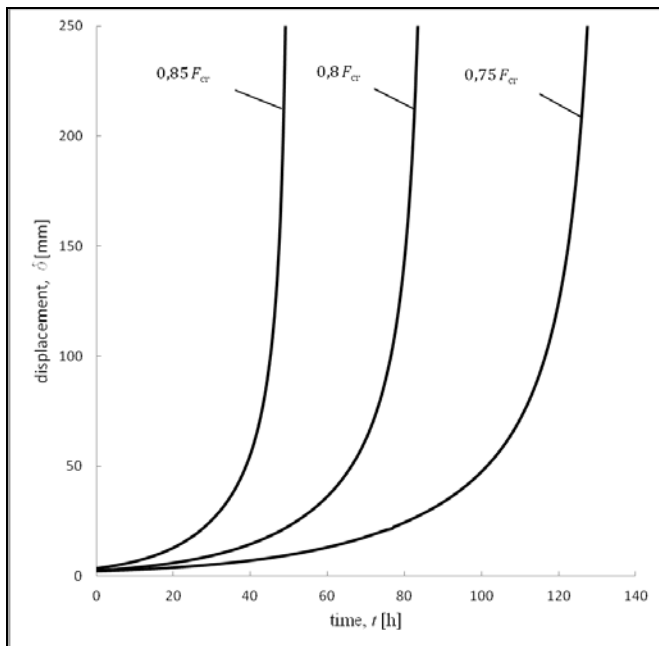


Fig. 6 Creep buckling curves for material B at 649°C

Table 2: Critical buckling times (h)

Load level	Material A		Material B
	$T = 538^{\circ}\text{C}$	$T = 649^{\circ}\text{C}$	$T = 649^{\circ}\text{C}$
$0.85 F_{cr}$	2550	6	50
$0.80 F_{cr}$	4950	11	85
$0.75 F_{cr}$	8300	19	125

The approximate critical creep buckling times obtained for two different chemical composition of carbon steels at the different temperatures are listed in Table 2. This times can be recognized as the values to which buckling curves asymptotically tends in the infinity.

Fig. 7 shows the comparison of material A buckling curves at both temperatures levels, 538°C and 649°C, while on the Fig. 8 the creep buckling curves of both materials A and B at the same temperature level condition 649°C are displayed for clearer comparison.

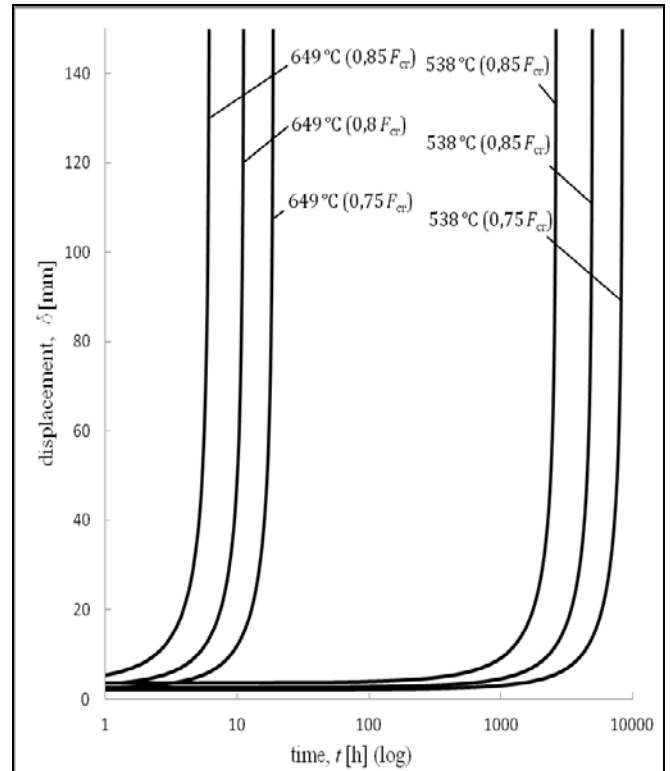


Fig. 7 Buckling curves for material A at 538°C and 649°C

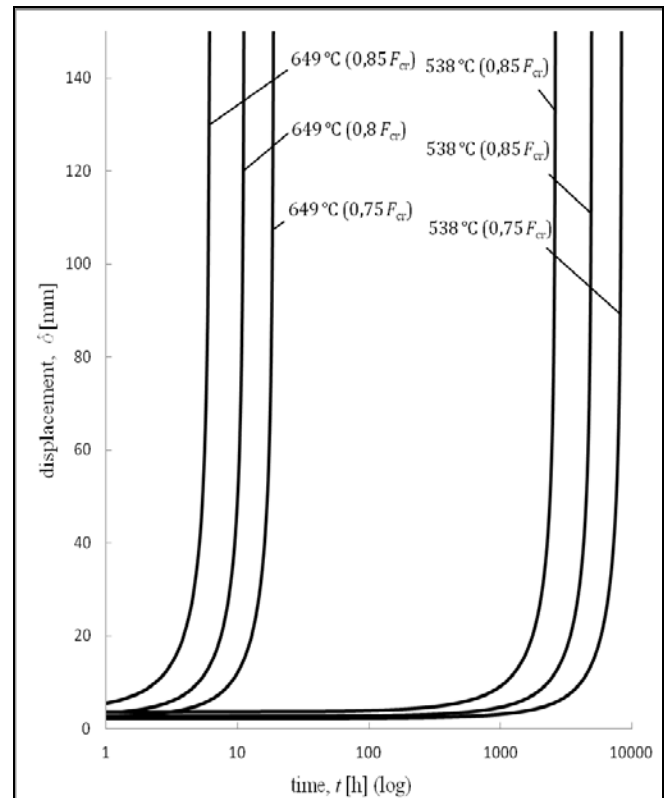


Fig. 8 Buckling curves for material A and B at 649°C

4. Concluding remarks

High temperatures which are caused e.g. by fires have significant influence to collapse time of frame structures. Numerical simulation of creep buckling is a fast way of prediction of such phenomena. From obtained results it can be concluded that material B is more creep resistant than material A. Furthermore, critical buckling time of material A rapidly decreases by temperature growth from 538°C to 649°C. Future research will encompass development of a creep buckling computer algorithm based on beam finite elements.

5. Acknowledgement

The research presented in this paper was made possible by the financial support of the Ministry of Science, Education and Sports of the Republic of Croatia, under the project No.069-0691736-1737 and No.069-0691736-1731.

6. References

- [1] Lanc, D.; Turkalj, G.; Brnic, J. Beam model for creep buckling analysis, in: *Proceedings of 5th International Congress of Croatian Society of Mechanics*, September 21-23, 2006, Trogir, Croatia, pp. 65-66.
- [2] Lanc, D.; Turkalj, G.; Brnic, J. Finite-element model for creep buckling analysis of beam-type structures, *Communications in Numerical Methods in Engineering*, Vol. 24 (11), 2008, pp. 989-1008.
- [3] Nguyen-Thanh, N.; Rabczuk, T.; Nguyen-Xuan, H.; Bordas, S.P.A. A smoothed finite element method for shell analysis, *Computer Methods in Applied Mechanics and Engineering*, Vol. 198, 2008, pp. 165-177.
- [4] Bathe K.J. Finite Element Procedure, London, Prentice-Hall, 1996.
- [5] Walczak, J.; Sieniawski, J.; Bathe, K.J. On the analysis of creep stability and rupture, *Computers & Structures*, Vol. 17(5-6), 1983, pp. 783-792.
- [6] Beljajev N.M. Soprotivljenje materijalov, Moscow, Fizmatgiz, 1959.
- [7] Buksa M. Numerical analysis of frame structure in creep regime, Faculty of Engineering of University of Rijeka, MSC Thesis, 2013.

COMPARISON OF THE EFFECTS OF INDIVIDUAL AND PRODUCTION ADJUSTMENT OF VEHICLES FOR LPG APPLICATION

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Abstract: The paper presents the results of developmental researches related to determining the influence of application of various systems for LPG on vehicle properties. On model Florida Zastava the following sequential systems were installed: Sequent 24 BRC, Omegas LR, e-G@S, Fast Lovato and Alisei N Zavoli. The results of comparative investigations obtained indicate the advantages of particular systems. The results of individual adjustment have been compared with the results of a production vehicle adjustment.

Keywords: VEHICLE, LPG, SEQUENTIAL SYSTEMS.

1. Introduction

Fossil fuels (around 99%) are still dominant as drive fuels for automobile engines, in spite of many attempts to introduce other alternative fuels (LPG, CNG, alcohol, hydrogen and others). In this paper, some experience in applying liquid petroleum gas and compressed natural gas on vehicles, as alternative fuels for dual drive, will be considered. All vehicles which use liquid fuels can be adjusted to application of gas, in bi-fuel systems. Which of the systems for LPG/CNG will be applied depends on the purpose of vehicle and type of main fuel. Long-term decision is that bi-fuel systems are applied on petrol engines. The main property of these systems is that engine is activated only by petrol or gas, according to attuned device, driver's desire or available fuel. The paper has analysed systems with gas injection applied on vehicles with plastic intake manifold. System for gas injection consists of the following important elements: electronic control unit (ECU), switch indicator, gas filter, gas pressure regulator, injector rail, gas temperature and pressure sensor.

To the existing electronic control unit of the system for petrol injection one more electronic unit is added, which makes the connection with the existing petrol system. System for gas injection is the system of new generation of dual systems (petrol-LPG/CNG). System for gas makes possible injecting of gas into each intake manifold separately. According to defined procedure, the engine starts functioning with fuel at start, and after certain period of time or achievement of given temperature the control unit switches the engine functioning to gas. The principle applied by electronic control unit for gas is calculating of injection time applied on gas injector. Control of engine is given to petrol electronic control unit, while electronic control unit for gas turns that information into suitable control form for gas. New gas systems can use different types of injectors in dependence on application conditions. Electronic control unit for gas calculates the time of gas injection by using specific information, such as pressure in injector, gas temperature, cooling liquid temperature, number of engine revolutions as well as input data of petrol electronic control unit (ECU).

In systems with auto-calibration, the initial adjustments are realized at a standstill, too, after installing the system for gas in vehicle. In general, the adjustment of system configuration is realized when the engine is not running. After that, the auto-calibration procedure is started, where adjustment is performed according to the demands of the system producer. After the completion of auto-calibration procedure, each system will define its system map. The map is constructed on the basis of two pieces of data: engine rpm and petrol injection timing. In case that you are not satisfied with auto-calibration, possible modifications can be realized by optimization of map value on gas, i.e. map coefficients loaded during automatic calibration process, both at minimum and beyond idle stroke range.

2. The application of sequential systems for LPG

When selecting the sequential system for LPG, the following must be taken care of:

- That the system for gas is homologated according to valid regulations.
- That the gas tank with strengthening must also be homologated according to valid regulations; in addition to that, gas tank must satisfy the time condition for safe installing.

At the market, there is a wide range of sequential systems for gas injection, produced by both the leading system producers and the unsuccessfully licensed and new producers. The worst version is when the installer composes the system himself, without any examinations and tests. That is especially bad when performed by a bad installer with the false aim of making it less expensive. Based on previous experience in the application of vacuum gas systems and on market offers, the following systems for gas injection were selected for developmental investigations: Sequent 24 BRC, OMEGAS Landi Renzo, e-G@S, Fast Lovato, Alisei N Zavoli.

All the systems were installed into the engine compartment; tank with support was installed into luggage compartment, while the commutator for the selection of fuel type was installed on the dashboard. The proposed solutions for installing the gas system should provide:

- additional installing of optional drive units on the vehicle (A/C, servo controller etc.)
- standardized installing for all the versions of one vehicle model
- standardization of parts which are to be installed.



Fig. 1 Vehicle Florida 1.6 In L- OMEGAS Landi Renzo

Fig.1 shows the installing of device OMEGAS Landi Renzo. ECU for gas is installed next to the petrol one. The injectors are installed on the upper side. Vaporizer is connected to the car battery support. The final aim is standardization of the linking point of gas system elements, within limits of the observed vehicle model.

Basic regulation is performed without load, at a standstill:

- at idle stroke
- at 3000o/min.

The recommendation is to carry out the necessary corrections in driving after each basic adjustment.

3. Analysis of the influence of applying various systems for gas

With the aim of determining the effects of application of various systems, the following investigations are realized:

- properties of engine/vehicle which uses petrol/LPG
- properties of engine/vehicle with various systems for LPG.

3.1 The investigation of vehicles on dynamometer rolls

The paper includes the investigation of vehicles on dynamometer rolls, Fig.2, with the aim of determining the effects of application of various systems for LPG.



Fig. 2 Investigations of vehicles on rolls

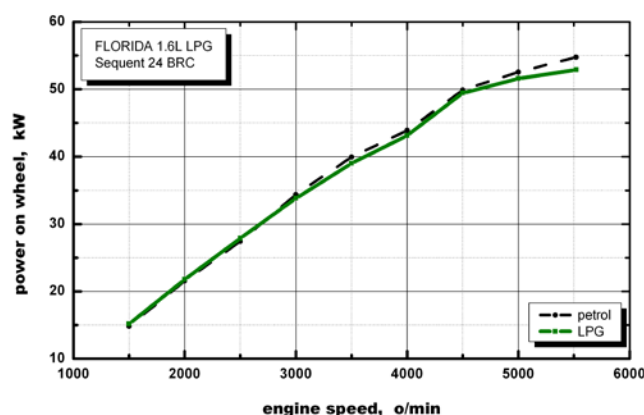


Fig. 3 Florida In 1.6L –Sequent 24 BRC

The selected methodology for measuring power on vehicle wheel provides fast and accurate comparative measuring with the aim of observing the influence of various changes on force-speed properties of the vehicle. The procedure makes it possible to use the measured values in order to calculate the external speed property of the engine. Owing to the applied adjustment of measuring to standard conditions, good comparability of the results is provided, because varying of important factors is eliminated.

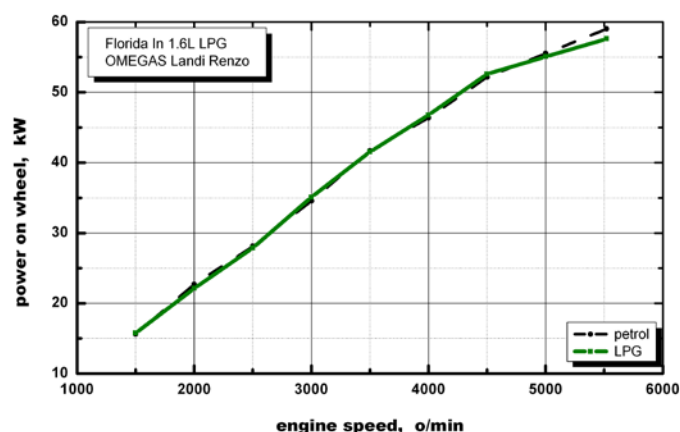


Fig. 4 Florida In 1.6L- OMEGAS LR

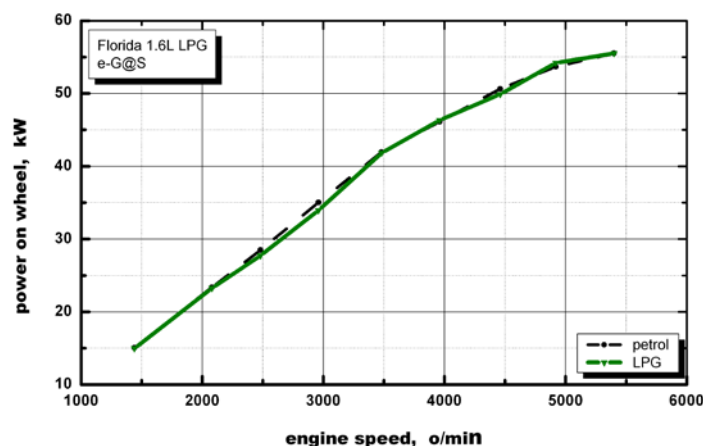


Fig. 5 Florida In 1.6L- e-G@S

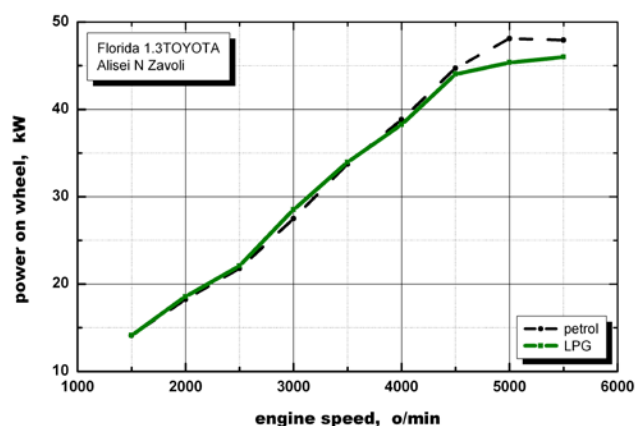


Fig. 6 Florida 1.4- Alisei N Zavoli

Fig. 3, 4, 5 and 6 show the effects of application of various systems on vehicle Florida, with multipoint system for petrol, which satisfies Euro III. Different systems are programmed in different ways and they provide different results. At smaller r.p.m. mainly all systems for gas function well. At higher r.p.m. the differences are obvious, especially in programming without correction. Persistent correction of adjustments can lead to the desired congruence of behaviours when using petrol and LPG, but that should not be the only aim.

3.2 Exploitation investigation of vehicles

When optimizing the programming process, the initial adjustment must be corrected by measuring made on engine brake, on dynamometer roll and, subsequently, in exploitation conditions. Exploitation investigations included:

- Comparative measuring of maximal speed with petrol – LPG

- Comparative measuring of acceleration with petrol – LPG
- Comparative measuring of elasticity with petrol - LPG
- Comparative measuring of consumption petrol - LPG (mixed test, urban driving)
- Optimization of system operating
- Recording of performances.

Comparative measuring of maximal speed with petrol/LPG. A sequential system for gas injection OMEGAS Landi Renzo was installed into the vehicle Florida In 1.6L. This vehicle behaved almost identically with LPG as with petrol.

Table 1: Maximal speeds – comparative display.

Vehicle	V ₀ =0 km/h		V ₀ =40 km/h	
	petrol	LPG	petrol	LPG
Florida In 1.6L	167,6	165,97	164,6	164,7

Comparative measuring of acceleration and elasticity with petrol/LPG. Table 1 and Fig. 7 show the comparative results of acceleration measuring (0 - 120km/h). A minor degradation of speed occurred with LPG drive. As for elasticity measuring, Fig.8, congruence with LPG drive was even better than with petrol.

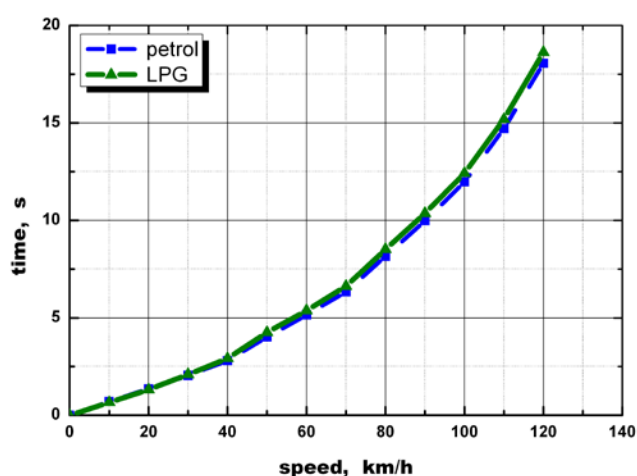


Fig. 7 Florida In 1.6L- acceleration 0 - 120km/h

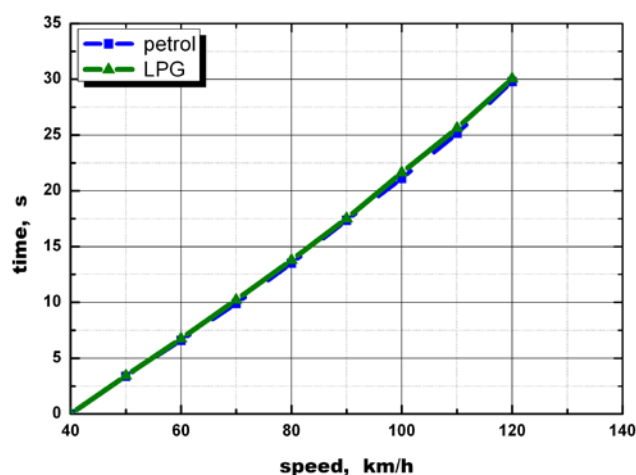


Fig. 8 Florida In 1.6L- elasticity 40 – 120km/h

Table 2: Fuel consumption- vehicle Florida In 1.6L LPG

	Fuel consumption (l/100km)	
	LPG	PETROL
urban	9.52(+12.4%)	8.47
combined	8.0(+10.5%)	7.24

Comparative measuring of consumption with petrol/LPG. In mixed test conditions, litre consumption with LPG was +10.5% higher, while in urban driving conditions litre consumption with gas was +12.4% was higher.

Fig. 4 and table 2 show the results of optimization on the vehicle Zastava Florida In 1.6 L TNG with OMEGAS Landi Renzo system for gas injection. Comparative results of measuring power on the wheel for petrol/LPG indicate insignificant decrease of power on the wheel in case of gas application, since the system was well adjusted, in high regime. The final aim of the performed adjustment was not obtainment of identical power for petrol and LPG, but optimization of power, consumption and emission with LPG. Major attention was given to economic effects of optimization, i.e. reduced consumption as a result of the adjustment.



Fig. 9 Vehicle Punto Classic LPG

As for adjustments on the vehicle FIAT Punto Classic LPG, where system for LPG was factory-installed, optimization was realized with the aim of achieving the same vehicle properties for driving with both petrol and LPG, which was ultimately accomplished according to the published data of the producer [8]. The principle of identical vehicle properties for both petrol and LPG is a feature of factory-installed adjustment for all producers.

Table 3: Technical characteristics vehicle's FIAT Punto CLASSIC LPG 1.2[8]

Engine	1.2 8v LPG	
total displacement, cm ³	1242	
compression ratio	9,8:1	
emission	Euro 4	
FUEL	LPG	PETROL
max. EEC power, kW/KS	44/60	44/60
rpm n _p , o/min	5000	5000
max. torque, Nm/kgm	102/10,4	102/10,4
rpm n _m , o/min	2500	2500
engine idle speed	900±50	

Table 4: Performance[8]

Performance	LPG	PETROL
top speed, km/h	155	155
acceleration 0-100km/h, s	14.3	-

Such method of adjustment has definitely influenced the increase of consumption in litres when driving with gas – for over 20%. Table 5 shows the comparative consumption values for vehicle with petrol/LPG. The effects of adjustment are in line with the recommendations of gas system producers. The obtained gas emission is more favourable, which was expected.

Table 5: Fuel consumption according to Directive 2004/3/EC [4]

	PETROL (l/100km)	LPG (l/100km)
urban	7.1	9.2 (+22.8%)
extra urban	4.8	6.0 (+20.0%)
combined	5.6	7.2 (+22.2%)
CO ₂ emissions, g/km	133	116 (-12.8%)

4. Conclusion

Development and introduction of new solutions in car industry is a necessity, especially bearing in mind ever stricter market demands and valid regulations. In addition to that, it is necessary to improve the methods for estimation of performed interventions constantly. The presented results indicate the influence of installed sequential systems for LPG on vehicle properties, which is essential in vehicle development.

References

- / 1 / Milovanović M., Petrović S., Vitošević N., Spasojević S.: Application of gas as alternative fuel, ECO VARNA 2006, Varna, May 2006, pp. 9-15, ISBN 954-20-00030.
- / 2 / Milovanović M., Dimitrov A., Vitošević N., Uremović Š.: Experience in application of liquid petroleum gas on vehicles, ECO VARNA 2007, Proceedings, Varna, May 2007, pp. 9-16, ISBN 954-20-00030.
- / 3 / Milovanović M., Dimitrov A., Vitošević N., Uremović Š.: Investigation of influence of programming LPG injection systems on vehicle behaviour, ECO VARNA 2008, Varna, Proceedings, May 2008, pp. 9-16, ISBN 954-20-00030..
- / 4 / Milovanović M., Demić M., Jovanović S., Popović M.: Diagnostics of sequential systems for gas on motor vehicles, 10th International Automotive Congress CAR 2011, CAR2011_1107, Faculty of Mechanics and Technology, Pitesti, Romania, 2-4 November 2011, ISSN 1453-1100.
- / 5 / Milovanović M.: The analysis of the influence of sequential systems for gas on motor vehicles, trans&MOTAUTO '12, Varna, 2012.
- / 6 / ALIMENTAZIONE MOTORI CNG, Manuale, Fiat Auto S.p.A. – After Sales Training, 2004.
- / 7 / Milovanović M.: Presentacija FIAT PUNTO CLASSIC TNG, FIAT Automobili Serbia, Beograd, 2009.
- / 8 / FIAT PUNTO, Fiat Group Automobiles S.p.A. - Customer Services - Technical Services - Service Engineering Largo Senatore G. Agnelli, 5 - 10040 Volvera - Torino (Italia) Print no. 603.97.XXX - 09/2009 - 1 Edition.
- / 9 / Milovanović M.: Vozila sa pogonom na gas, monografija, Univerzitet u Kragujevcu, Fakultet inženjerskih nauka Kragujevac, Kragujevac, 2012, ISBN 978-86-86663-85-6.

COMPARATIVE ANALYSIS OF THE BODY VIBRATIONS OF NEW CARS EQUIPPED WITH THREE DIFFERENT TYPE OF ENGINES

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Abstract: The paper presents the results of comparisons tests carried out on one model (Fiat Bravo model 198 produced in 2010) of new cars equipped with three types of engine: Version 54A with the 1.4BZ 90CV CD spark-ignition engine, Version 54G with the 1.4BZ 120CV CD spark-ignition engine equipped with a supercharging system and Version 54W with the 1.6D 105CV diesel engine. The car body vibrations experimentally determined in several specific repeatable points, i.e. behind the front side indicator and behind the passenger handle, were compared. A PSV-400 laser Doppler vibrometer made by Polytec was used to measure vibration velocities. The vibrometer directly measures two quantities: displacement and velocity. In the investigated case, vibration velocity turned out to be the variable supplying better diagnostic information. Vibrations were measured for the car standing on its wheels and for the car jacked up to reduce the influence of the car vibration damping systems on the measurement results. The latter are presented in the form of comparative diagrams. Moreover, the fast Fourier transform was used to determine the frequency distribution. Prior to that the signal was subjected to conditioning operations in time domain, such as parametric windowing and filtering. On the basis of the results the effect of the drive unit on the behaviour of the car body can be assessed for different engine types and rotational speeds. It is shown that the way in which the engine is mounted affects the vibrations of the car.

Keywords: LASER DOPPLER VIBROMETRY, VEHICLE BODY VIBRATIONS, VIBRATION VELOCITY, SPARK-IGNITION ENGINE

1. Introduction

Mechanical vibration is a phenomenon consisting in the conversion of kinetic energy into potential energy, which is further converted into kinetic energy, etc., until the phenomenon dies out [1 - 3]. The measurement of mechanical vibrations depends on the system's number of degrees of freedom (DOF).

Since a mechanical system, such as the combustion engine, has an enormous number of DOFs, vibration diagnostics is highly complicated. In order to avoid a huge number of computations, physical systems are interpolated to systems with a known number of DOFs. In such systems the components with the smallest mass are represented by deformable constraints while components with a larger mass are represented by material particles or rigid bodies [3].

For (vibroacoustic kind of) vibration, measurements the system is assumed to be continuous, which means that the number of freedom points is determinate and that it is necessary to change over from discretization based on differential equations to continuity based on integral calculus [4]. Therefore one can say that vibroacoustic vibration measurement is approximation already at the detection level where system discretization is approximated by continuity.

Moreover, now is very modern to consider of vehicle vibration in ergonomic aspect – in this case in effects of vibration on human health. The effect of vibrations on the human organism has been widely described in the specialist literature [6], focusing on:

1. The values of the parameters (velocity, displacement, etc.) describing vibrations.
2. The way in which vibrations are transmitted to the human body.
3. The individual physiological characteristics.

The natural vibrations of most of the human organs range from 3 to 25 Hz. If such vibrations are transmitted to the human body, resonance may arise. This may result in the dislocation of an organ and in the extreme case, in its damage. The exposure of the human organism to general-impact vibrations can be assessed with regard to vibration parameters, such as acceleration, displacement and velocity, according to the criteria:

1. The harmfulness limit.
2. The nuisance limit.
3. The comfort limit.

2. Investigated objects

Three vehicles: Fiat Bravo Model 198 54A cars with respectively engine: 1.6 105CV CD, 1.4BZ 90CV CD and 1.4BZ 120CV CD were tested. The latter engine model was equipped with a supercharging system. The specifications of the tested cars with the two different engines are shown in the tab. below.

Table. 1: Comparison of tested engines specifications

Specification	Type of engine		
	1.6 105CV CD	1.4BZ 90CV CD	1.4BZ 120CV CD
Engine cubic capacity	1598 cm ³	1368 cm ³	1368 cm ³
Engine horsepower rating	105 hpm	90 hpm	120 hpm
Engine mounting	front crosswise	front crosswise	front crosswise
Type of camshaft	OHC	OHC	OHC
Cylinders	bank	bank	bank
Number of cylinders	4	4	4
Number of valves per cylinder	4	4	4
Weight	1320 kg	1205 kg	1260 kg

The structure of a motor vehicle without its plating is shown in fig. 2. The crucial parts and the structure of the individual beams are shown in detail. Test results indicate that the side frame, through which vibrations are transmitted to the measurement sites, is critical. The structure of the particular components is layered as shown in fig. 1.

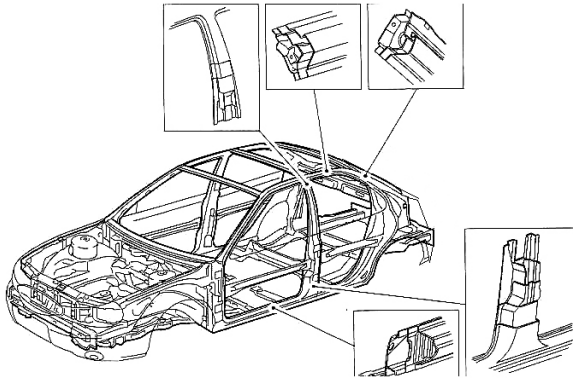


Fig. 1 Investigated object without plating

3. Measurement system and methodology

Laser Doppler vibrometry (LDV) was used for the investigations. LDV is based on the Doppler effect, which consists in a change in the length of the light wave received by the target if the latter is moving relative to the source.

Properties of vibroacoustic signals, often wrongly considered to be synonymous with vibro-acoustic vibrations are widely described in the literature [1 – 10]. Nevertheless, till nowadays, definition of vibroacoustic signals and vibroacoustic vibration has not been unified. It is assumed that the vibroacoustic vibrations are narrower expression, on one specific medium. The vibroacoustic signals phrase refer to the total signal issues, i.e. both vibrations and activated discrete representation of these vibrations and in particular the variables of their characteristic. Note complex level of vibration diagnosis, as the physical system, has a large number of degrees of freedom. To avoid the large number of calculations, physical systems are interpolated to such, in which the number of df is known. In these systems, the elements of lowest mass are assumed to be deformable, while the heavier elements is taken as material points or rigid solids [4]. One of the most quoted literature [2] defines vibroacoustic signals as a general dynamic phenomena; that take place in machines, equipments (devices) and special constructions. These phenomena are vibration, noise, air and sound material and the medium pulsation in workspaces machines. They occur in a wide frequency range from very low, almost zero, a very high level of MHz. Vibroacoustic vibrations are often mistakenly used as a synonym for dimensions characterizing them. There are the following physical dimensions used to quantitatively describe the process of vibration [5]:

1. Displacement.
2. Relative displacement.
3. Velocity.
4. Relative velocity.
5. Acceleration
6. Harmonic movement phase

Dimensions characteristic for vibroacoustic vibrations are measured with different methods, from which should be distinguished piezoelectric accelerometry and recently more and more popular laser vibrometry. The measuring method is closely related to the measured value. For accelerometry, the directly measured dimension is relative acceleration, and in the case vibrometry, the displacement and the relative velocity. Other dimensions are measured in diagnostic systems, but are the result of transformation of the basic value. Performing measurements of vibroacoustic vibration, it is assumed that the system is continuous, which indicates determined number of points of freedom and also the need to move from the discretization, based on differential equations for continuity, based on the account integral [8].

The principle of operation is shown in the fig. 2. The generated wave of the frequency f_0 is sent to both the photodetector and in the object direction oscillating with f_d frequency. In the path directed toward the object, is Bragg module and its position in the head is set up to gain (at an integer multiplicity of wavelength). Summation signal is sent to the detector.

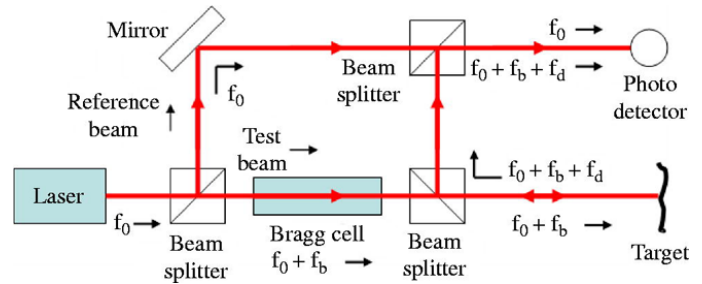


Fig. 2 LDV system [11]

In the experiment below, laser head with neon – helium laser was used. The beam path length of the reference is constant in time (as occurs in the head secured so that thermal effects are negligible). However, changing the optical length to the analyzed object, causes a frequency shift of the diagnostic beam (according to the Doppler effect). The study was performed using vibrometry, which parameters are shown in the table, given below [9].

A laser probe is the transmitting-receiving device. After it is reflected and returns to the scanning head the laser beam hits a lens. This measuring method allows one to directly measure velocity and relative displacement [4]. Any other parameter is a derivative of the above quantities. Velocity is converted into voltage proportional to frequency shift. Displacement is measured by counting the occurrences of areas generating specific wavelengths.

A diagnostic circuit consisting of a Polytec PSV-400 (PSV-I-400) vibrometric probe, an OFV-5000 controller and a PSV-W-400 supervision & acquisition system was used in the experiment. The controller and the supervision system were contained in a dedicated mobile enclosure. Vibration velocity was measured behind the side indicator and behind the rear passenger door handle. The measurements were performed in the neutral gear with and without forcing the crankshaft rotational speed of 2000 min.⁻¹. The measurements were carried out for a jacked up car and a car standing on its wheels. The two cars were investigated in the same conditions. Figure 3 shows a photograph of the test rig and the place (behind the passenger handle) on which the laser beam falls.



Fig. 3 Place of beam reflection on vehicle body during investigation

The results are shown in the form of diagrams in which the measured velocities of the vibrations generated by motor vehicles are compared. The waveforms were registered during 2 s long tests being part of the measurement lasting 4 s and involving 4096 samples in each case. Also frequency spectra (obtained through the Fourier transform) are shown in the figures.

4. Results

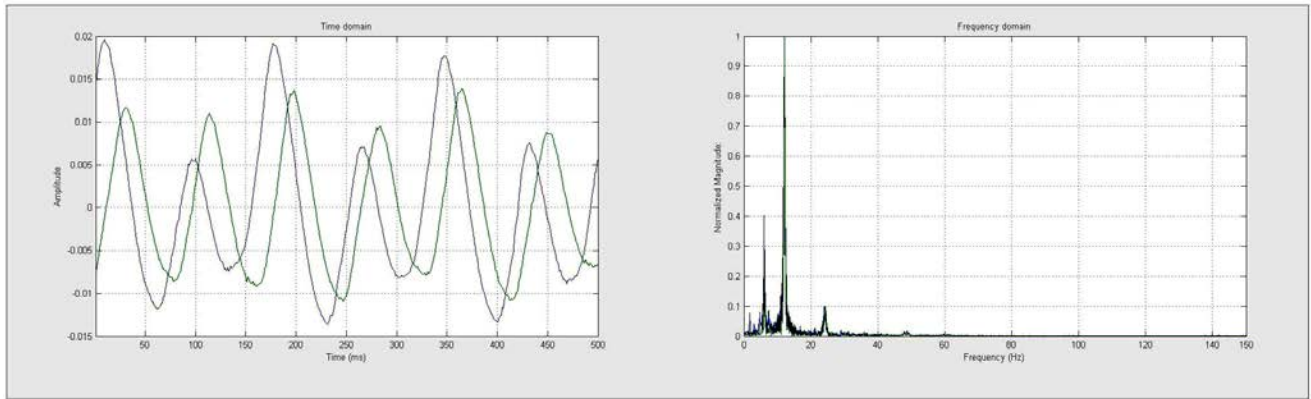


Fig. 4 The investigation of ground bases influence, 1.4BZ 90CV CD, green – lifted on

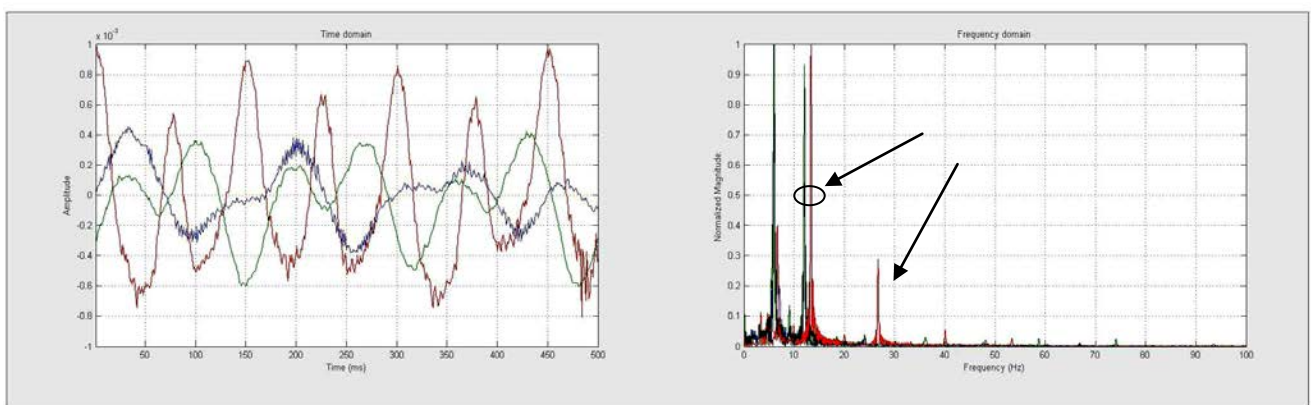


Fig. 5 The comparison of vehicles bodies vibration: blue - 1.4BZ 90CV CD, green - 1.6 105CV CD, red - 1.6 105CV CD, idle (~900rpm)

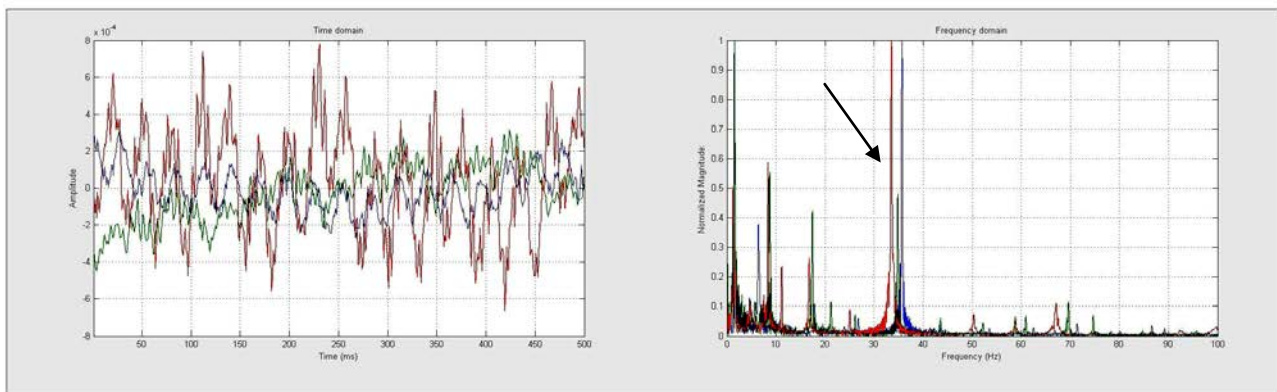


Fig. 6 The comparison of vehicles bodies vibration: blue - 1.4BZ 90CV CD, green - 1.6 105CV CD, red - 1.6 105CV CD, idle (~2100rpm)

Results is showed on three figures (4 – 6). First step, during researchers was based on checking of influence of floor base on vibration. In first step (fig. 4, blue) vehicle was standing on wheels, in second step car was lifted on. The character of vibrations in time domain (which is confirmed in frequency domain – harmonics were on this same values) is constant (in sense of phase) but magnitude of signal is bigger for standing car. This phenomenon was checked and it was repeated. So – in next step researchers was making for car standing (via wheels) on the floor.

Fig. 5 shows results of LDV vibration signals for three cars on an idle gear. Harmonics are on this same value of frequency. There is a small different between second, dominant harmonic

(indicated in fig. 5b) for spark and diesel engine. Moreover diesel engine generate one extra harmonic (indicated in fig. 5b) on frequency 28Hz.

Fig. 6 shows this same kind of experiment but for bigger crankshaft speed. In this case widely spread of frequencies is showed. Harmonics for spark ignition engines are equal (in sense of frequency value) to approx. 15Hz. After that it spreads bigger value (indicated in fig. 6b). In this case considerable distortion of vibration (fig. 6a) is noticeable for all kinds of engines.

5. Conclusions

1. As it was shown, frequency may have an implications for the health and comfort of vehicle travelers.
2. The vibration signal, measured with force has non-stationary nature, as well as signal measured without force has also non-stationary nature.
3. Spark-ignition engines in all measurements generate smaller pattern of vibration compared with a diesel engine (it wasn't presented in figures). Moreover vibration of diesel engine generates bigger distortion.
4. Diesel engine might generate vibroacoustic signal with major magnitude (in comparison to spark ignition) because of process and bigger pressure in combustion chamber.
5. Turbocharged engine generate vibrations with bigger stabilization then rest. Is it because the load in all cylinders is more defined.
6. Minimizing the potentially dangerous effects of vibration is possible not only by getting a better vehicle suspension and the separation of the driver, but also by the use of the compressor, which increases the frequency of the dominant harmonic outside the hazardous area. However, it is now rarely used method because it has negative impact on an electronic control of engine supply at low engine speeds (and it is more expensive).

Literature

- [1] P. Bogus, *Wykorzystanie nieliniowych metod analizy sygnałów w diagnostyce silników spalinowych*, Wyd. Politechniki Poznańskiej 2006.
- [2] C. Cempel, *Wibroakustyka stosowana*, Warszawa, PWN 1989.
- [3] C. De Silva, *Vibrations Fundamentals and Practice*, NY, CRC Press 2000.
- [4] J. Giergiel, *Drgania mechaniczne*, Kraków, Uczelniane Wydawnictwa Naukowe – Dydaktyczne 2000.
- [5] T. Kucharski, *System pomiaru drgań mechanicznych*, Warszawa, WNT 2002.
- [6] R. Markiewicz, *Dźwięki i fale*. Poznań, Wyd. Naukowe Uniwersytetu im. Adama Mickiewicza 2004.
- [7] R. S. Singiresu, *Mechanical Vibrations*. Singapore, Prentice Hall 2005.
- [8] Bosch Technical Library, *Control systems of diesel engines*, Warszawa, WKŁ 2004.
- [9] Dudzik G., Wąż A., Kaczmarek P., Sotor J., Krzempek K., Soboń G. J., Antończak A., Abramski K., *Multichannel flexible fiber vibrometer*, Defense, Security, and Sensing 2011: Emerging Technologies and Laser Sensors and Systems, 2011.
- [10] F. J. Harris, *On the Use of Windows for Harmonic Analysis with the Discrete Fourier Transform*, IEEE Vol. 66, January 1978.
- [11] PSV-400 Scanning Vibrometer - Technical Data, www.polytec.com/eur/158_184_4.asp.

A COMPARISON OF FUEL CONSUMPTION BETWEEN THE NEW EUROPEAN DRIVING CYCLE TEST AND THE NATURAL OPERATION OF A VEHICLE

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Abstract: There are many changes in the automotive industry which leads to improved to safety and reduce fuel consumption. A new design of vehicles are being modernized, reducing aerodynamic resistances and the weight of vehicle units. However it is forgotten about the same time changing and updating the fuel consumption's tests. The cars are tested with New European Driving Cycle test which based on directive 91/441/EEC (26 June 1991). It's been 23 years. NEDC was developed at a time when European vehicles were lighter and less powerful. The test offers a stylized pattern for low speed acceleration ($a = 0.89 \text{ m/s}^2$), speed, ride at idle, but temporary increase is much steeper and more dynamic in practice, in part due to the excess capacity of modern engines.

This paper presents a comparison of fuel combustion Polish users registered on the famous automotive's forum between factory data vehicles selected. As a result, it is hard for drivers to reach the certified values in practice.

The new version of the driving cycle should be more realistic to the everyday use of additional equipment and gadgets that are installed in modern vehicles.

Keywords: FUEL CONSUMPTION, VEHICLES, DRIVING TEST, OPERATING CONDITION, COMBUSTION ENGINE

1. Introduction

Fuel consumption by modern road vehicles is an interesting parameter of all users and producers. This is a consequence of the significant share of fuel costs in total transport costs [1].

In order to standardize the measurement of fuel consumption in the European Union in 1970 line directive 70/220/EEC [2] came into force as a part of the regulation ECE vehicles (the latest version is defined by ECE R83, R84 and R101). The New European Driving Cycle (NEDC) test was introduced. It aims to assess the level of emissions from car engines and fuel consumption in cars. NEDC is supposed to represent the typical use of the car in Europe. It consists of four repeated ECE -15 tests - urban driving cycle (UDC) and the Extra Urban Driving Cycles test (EUDC). The research of cars, weighing less than 3500 kg, which were equipped with engines with spark ignition and diesel engine are performed on a chassis dynamometer - roller dynamometer with DC motor or asynchronous AC motor [3]. The measurement of the test starts with a cold engine and is operated by a well-defined procedure for cyclic acceleration, braking and shifting, using the exhaust gas composition analysis. The nature of its ride from the beginning to the end is clearly defined, the car does not move and goes to the ideal "way" - rolls. In the design of the test methods it is pointed out that the motion characteristic of the vehicle in the natural operation is the variable speed which is mapped by means of its profile during the course of the speed. This profile, in operational conditions, has a random character.

2. Dynamometer tests

Urban Driving Cycles (UDC) has been designed to represent typical driving conditions busy European cities. It is characterized by a low engine load, low flue gas temperature and a maximum speed of 50 km/h- Figure 1.

The average speed during the test is 19km/h and the theoretical distance covered during the cycle is 1,013 km.

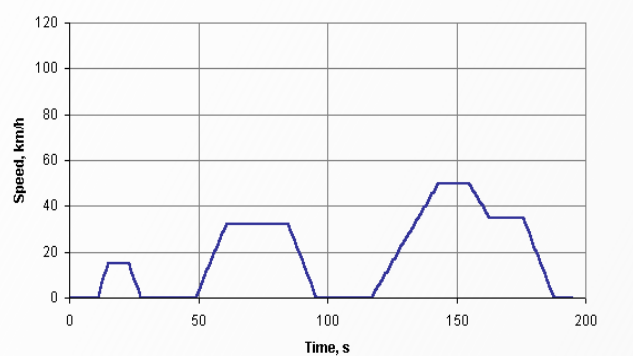


Fig. 1 UDC test [4]

In 1990 was introduced EUDC (Extra Urban Driving Cycles). It was designed to represent a more aggressive routes and highways, had high modes determine the speed. The velocity profile shown in Figure 2 below.

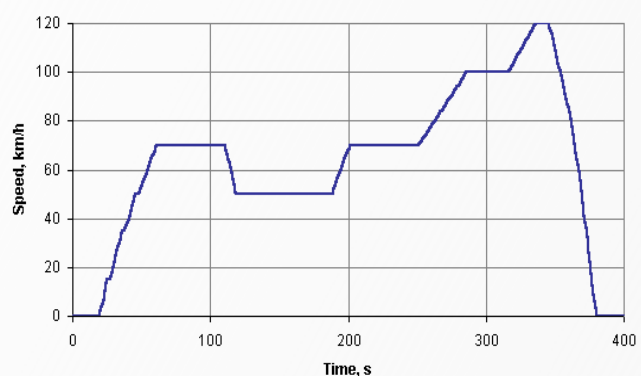


Fig. 2 EUDC test [4]

The Effective running time of test is 400 s while theoretical distance traveled in one cycle is 6,955 km it follows the average speed during the test: 62, 6 km/h.

The combined effect of the two tests UDC and EUDC was the New European Driving Cycles (NEDC). It consists of a recurring cycle of four ECE-15-UDC and one EUDC cycle, Figure 3.

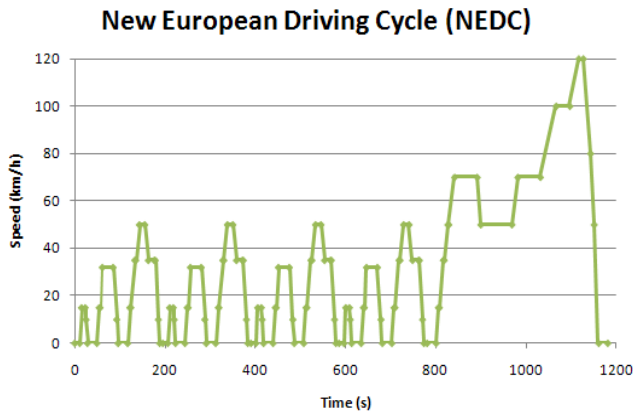


Fig. 3 NEDC test

The above-described tests are used all the time in the determination of secondary and urban vehicle fuel consumption. The car is tested at a temperature of about 25 °C, no air resistance and for any possible additives are excluded, which may further increase consumption of energy and fuel, in which the vehicle is equipped, for example: lights, heating and an air conditioning.

3. Investigated objects and the results

Fuel consumption determined in a test on a chassis dynamometer is not determined by measurement (weight or volume) of fuel actually consumed by the engine, but analytically based on calculations made taking into account the emission of exhaust components.

Referring to the sentence above the analysis has been subjected to attempt a population of 85 different models of cars with the most popular engine in its model, the weight of which does not exceed 3500 kg. Vehicles are assigned to the appropriate classification of vehicles. It was compared to the average consumption declared by the carmaker to the natural operation of the vehicle. Actual fuel consumption was measured by more than 8106 users of the analyzed vehicles.

Based on the analysis of fuel consumption has been shown that the difference in fuel consumption between vehicle specifications given by the car companies and the actual driving is about 18,4 % higher- table 1 and figure 4.

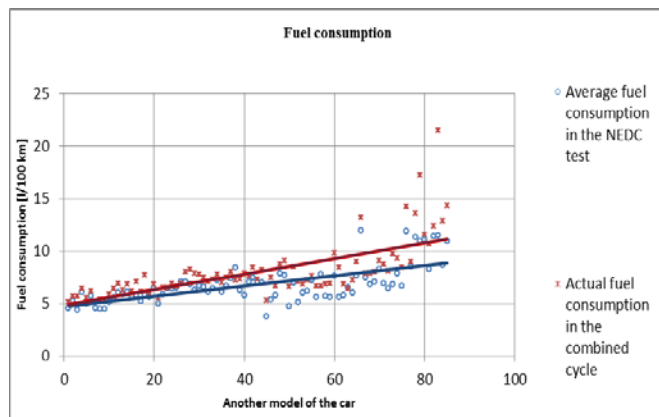


Fig. 4 A-segment mini cars

As the following analysis shows that in each segment vehicle classification exceeded consumption rates. The smallest indication to B-segment vehicles, or small vehicles. In contrast, the greatest indication are the most expensive cars of the segment, the segment

F. The following are shown examples of graphs for the small and the medium segments.

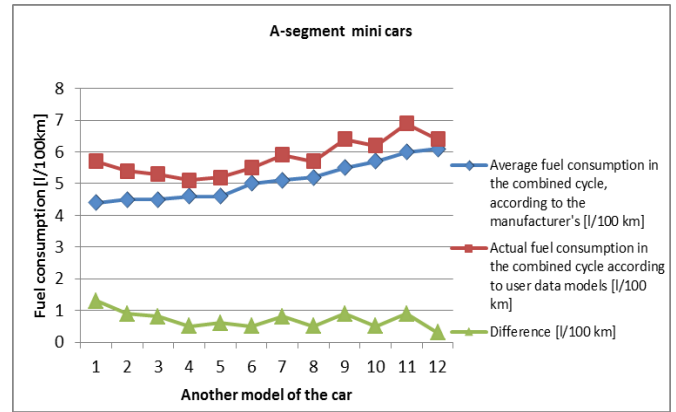


Fig. 5 A-segment mini cars

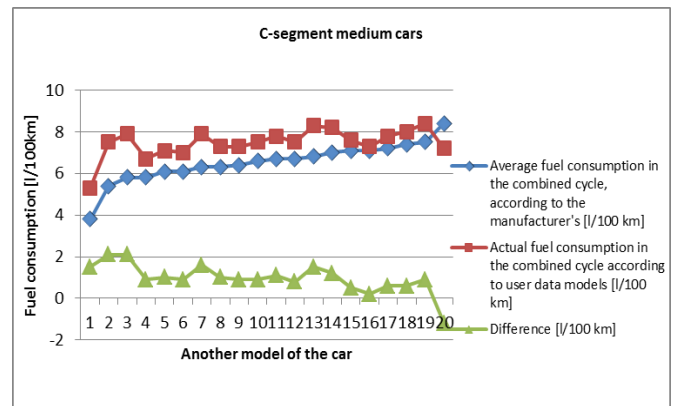


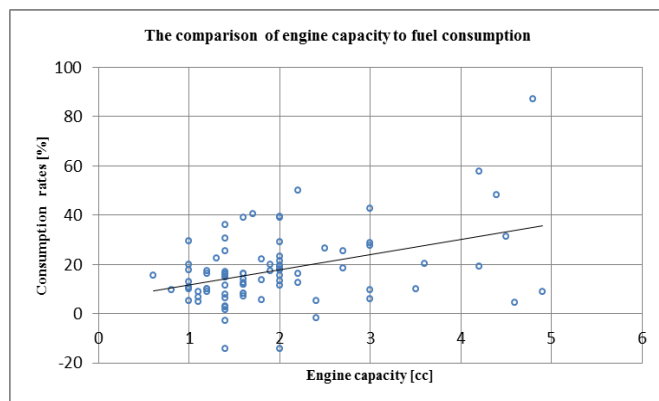
Fig. 6 C-segment mini cars

Table 1: Comparison of results

Car classification	A-segment mini cars	B-segment small	C-segment medium	D-segment large	E-segment executive	F-segment luxury
Number of analyzed models	12	15	20	17	11	10
The sum of opinions vehicle users	8106					
Average fuel consumption in the combined cycle, based on vehicle specifications [l/100 km]	5,10	6,07	6,53	6,35	7,64	10,45
Actual fuel consumption in the combined cycle according to user data models [l/100 km]	5,81	6,66	7,48	7,49	9,04	13,74
Difference [l/100 km]	0,71	0,59	0,96	1,14	1,40	3,29
The percentage difference between NEDC test and natural operation [%]	14,3	10,1	16,1	19,3	19,3	31,2
The average percentage of the difference between the NEDC test and natural operation [%]	18,4					

It seems advisable to clarify why the deviation fuel consumption in operation are greater as those designated in the dynamometer tests vehicles. The reasons could be many but, of course, seem to disregard basic tests on a dynamometer changes occurring in the operation of vehicles. In addition, it is used methodologically inappropriate determination of operational fuel consumption [5,6]. According to the below graph comparing the percentage difference in fuel consumption tests, it can be seen that the trend line is formed ascending towards a higher engine displacement expressed in cubic centimetres .

Fig. 7 The comparison of engine capacity to fuel consumption

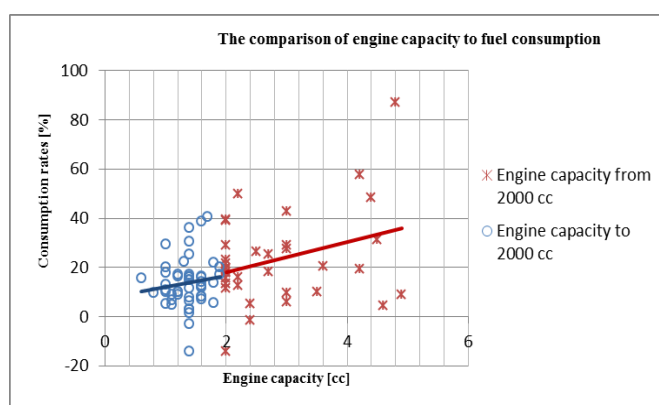


Dependence noted that the larger the displacement the fuel consumption is higher. Vehicle group was divided due to the displacement , is illustrated in table 2 and figure 8.

Table 2: The comparison of engine capacity to the average percentage difference between the NEDC test and natural operation

Engine capacity to [cc]	Percent of the vehicles in the sample [%]	The average percentage difference between the NEDC test and natural operation[%]
1600	40	12,5
2000	60	13,8
2500	80	15,1
4900	100	18,4

Fig. 8 The comparison of engine capacity to fuel consumption



The increase in fuel consumption with the increase of cylinder capacity is associated with a larger displacement engine, high dynamics and the nature of the operation of such vehicle by the user.

5. Conclusions

The analysis shows that the actual operation of the test vehicle , fuel consumption , significantly different from the test on a chassis

dynamometer . Consumption rates in the natural operation are much higher than declare that car manufacturers . The test vehicles consumed a whopping 18.4% more fuel than is in the technical data of their vehicles .

In addition, the relationship was found that the fuel consumption increases with the cylinder capacity of the vehicles tested .

In summary , the actual verification, any work on the fuel consumption should be done only under conditions of natural life . Evidently, it proves the inability of the NEDC test to represent real - natural style of driving and operating a car. It would create new tests measuring fuel consumption and emissions of harmful compounds with the dynamic development of the automotive industry. NEDC was developed at a time when European vehicles were lighter and less efficient. Test features a stylized pattern speeds for low accelerations ($a = 0.89 \text{ m/s}^2$) speed , fixed route and ride at idle , but temporary increase is much steeper and more dynamic in practice , in part due to overcapacity of modern engines. In addition , vehicles are tested without the burden that increase fuel consumption as heating or air conditioning . Also, the temperature during testing on a dynamometer is beneficial for reducing fuel consumption. Therefore, given by the manufacturers of the average fuel consumption should be taken with great caution .

As a result, it is difficult to achieve drivers certified values in practice. The new version of the driving cycle should be more realistic to the everyday use of additional devices and gadgets that are installed in modern vehicles , taking into account the increase in the growth of new car models . Tests should as much as possible to reflect the actual driving . It should be remembered consumption depends largely on driving style , condition of the vehicle , specific conditions of weather and how it is used .

Literature

- [1] A. RYCHLIK, *Metody pomiaru zużycia paliwa pojazdów użytkowych*, Eksploatacja i Niezawodność, nr 4/2006.
- [2] Directive 70/220/EWG, 1970.
- [3] J. MERKISZ , *Ekologiczne problemy silników spalinowych*, Tom I, Wydawnictwo Politechniki Poznańskiej 1998.
- [4] http://www.dieselnet.com/standards/cycles/ece_eudc.php
- [5] L. SITNIK, *Skumulowane zużycie paliwa*, Archiwum Motoryzacji, 2004, Vol. 7, nr 3.
- [6] L. SITNIK, *Ekopaliwa silnikowe*, Oficyna Politechniki Wrocławskiej, Wrocław 2004 r.

ROAD TRAFFIC SAFETY PERFORMANCE IN MONTENEGRO

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Abstract: According to WHO, more than 1.2 million people die in road traffic crashes every year and 50 million are injured or disabled. Over the last decade nearly all EU countries record a decrease in number of traffic casualties. However, in the same period Montenegro's figures generally point in opposite direction. The fatality rate on Montenegro's roads, measured as deaths per capita, is 50% higher than that of EU average; however, car ownership in Montenegro is considerably lower than the EU average. Having traffic safety figures so bad, efforts have been made in recent years to address this issue.

Keywords: TRAFFIC ACCIDENTS, ROAD DEATHS, (COUNTER) MEASURES

1. Introduction

More than a million people die each year on the world's roads. According to World Health Organization (WHO), approximately 1.24 million people die every year in car accidents and more than 50 million are injured, /1/. Road traffic injuries take an enormous toll on individuals and communities as well as on national economies. At the national level, road traffic injuries result in considerable financial costs, particularly to developing economies. It is estimated to cost countries up to 4% of their gross national product. In high-income countries, number of road deaths is decreasing in last few years, but low-income countries, such as Montenegro, saw increases over the same period. Current trends suggest that by 2030 road traffic deaths will become the fifth leading cause of death unless urgent action is taken.

Road safety in Montenegro is at low level. One of primary reasons is poor road infrastructure. Montenegro has a road network totaling approximately 7,000 km – with approx. 900 km of main and primary roads, 950 km of regional and secondary roads, and around 5,000 km of local roads. This is equivalent to a road density of 500 km per 1,000 km². This figure is broadly consistent with the density of some new EU member states (see Table 1), /2/. Regarding road infrastructure quality, Montenegro ranked only 107th, of 131 countries surveyed, for the quality of its road infrastructure. 90% of Montenegro's road network is high risk, including those segments with a high traffic volume, /3/. Also, 47% of the entire road network is in poor or very poor condition, reflecting inadequate maintenance. To improve the road safety situation on the main road network, costs an estimated €105–138 million.

Table 1 Road network density

	Road density	
	km of roads per 1000 km ²	km of roads per 1000 inhabitants
Montenegro	500	11.1
Southeast Europe, average	555	5.9
Albania	657	3.5
Bosnia and Herzegovina	427	5.6
FYR Macedonia	513	6.4
Serbia	500	5.2
New EU member states	1427	19.9
Czech Republic	1646	12.5
Estonia	1320	41.2
Hungary	1733	15.7
Slovenia	1007	10.2
Croatia	506	6.4

Other factors, such as the distribution and density of population and the country's geography, play a considerable role in determining country's road network. These effects become evident when making the comparison on a different measure of road density – viz. road kilometers per 1,000 people.

With this measure, with more than 11 km of road per 1,000 inhabitants, Montenegro is ahead of most of its regional comparators and comparable to those of the new EU countries, /5/.

Table 2 Number of vehicles in Montenegro

	2010	2011	2012	2013
Registered cars	164653	171973	173865	178662
per 1000 inhabitants	266	277	279	286

During last few years, the number of registered vehicles is around 200,000 counting all vehicles category and about 85% are passenger cars. The rate is approx. 286 passenger cars per 1,000 populations, (see Table 2), /4/. Compared to both the EU average and neighbors in the region, Montenegro's level of motorization is moderate (Fig. 1).

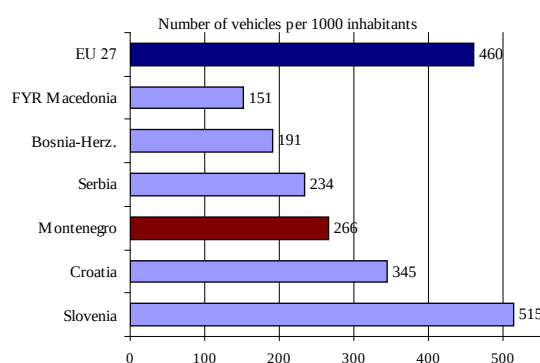


Fig. 1 Number of passenger cars per 1000 inhabitants in 2010

2. Road safety indicators

Number of road accidents, deaths and injuries in OECD countries is decreasing, despite larger number of vehicles. Number of accidents reduced by 15% in period 1990-2010, fatalities by 25%, while number of injuries remained the same. In EU-27 states in 2010 the number of fatalities was down to almost half of the figure from 2001, /5/. According to CARE – EU road accidents database, the largest reduction of number of fatalities achieved Malta, 48%, Cyprus, 28% Denmark 18% and Portugal, 16%.

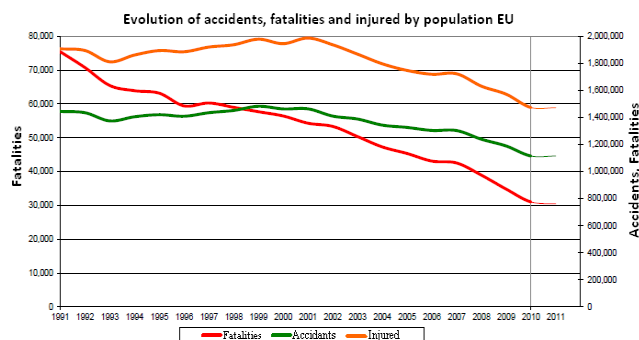


Fig. 2 Accidents indicators in EU

Countries of West Balkans as developing countries are trying to comply with the rules and regulations of the EU, including those in the field of transport. Despite that, all indicators of road safety in Montenegro have been increased over the previous ten years. Compared to 2000, in 2010 the number of road accidents went up 63.2%, fatalities by 17.3% and number of injured by 8.5%.

Over the last decade more than 1,000 people died on Montenegrin roads and more than 23,300 were injured. Mortality rate was the highest in period 2007-2009, over 10,000 accidents in 2008 and 122 killed in 2007 (see Table 3 and Fig. 3), /4/. However, in 2011 and 2012 Montenegro reduced number of road accidents and fatalities. The percentage of fatalities that occurred in crashes in 2012 was reduced by 52% compared with 2010 and by 62% compared with 2007. In spite of encouraging dates in last few years, studies show that number of fatalities in first six month of 2013 is already as high as in 2012.

Comparison of road safety performance depends somewhat on what indicator is used as a measure of exposure to risk; population, number of registered vehicles or distance travelled by motorized vehicles.

Fatalities per 100,000 head of population. This rate expresses the mortality rate, or an overall risk of being killed in traffic, for the average citizen. This is a particularly useful indicator to compare risk in countries with the same level of motorization.

Fatalities per 10000 registered vehicles. This is more objective indicator of situation on the roads. However, it's useful only when comparing the safety performance between countries with similar traffic and car-use characteristics.

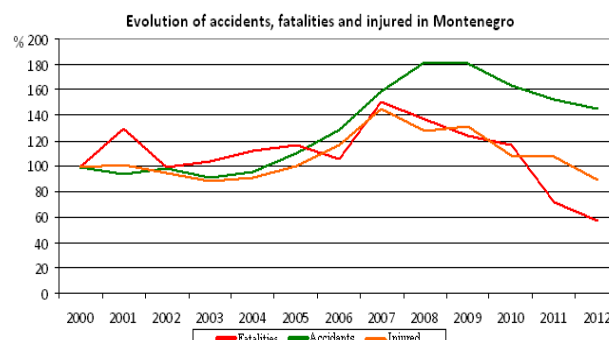


Fig. 3 Accidents indicators in Montenegro (2000=100)

According to OECD 2012 statistics, /6/, the rate in terms of fatalities per 100,000 populations in Montenegro in 2010 was 29.6. Comparing to both EU countries and neighbours in region, the risk of dying as a result of a road traffic injury on Montenegro roads is significantly higher.

Figure 4 shows the evolution of mortality expressed in terms of deaths per 100,000 population in European countries in 2011, /7/, and in EU-27, Montenegro and its neighboring countries in 2010 (*), /6, 8/.

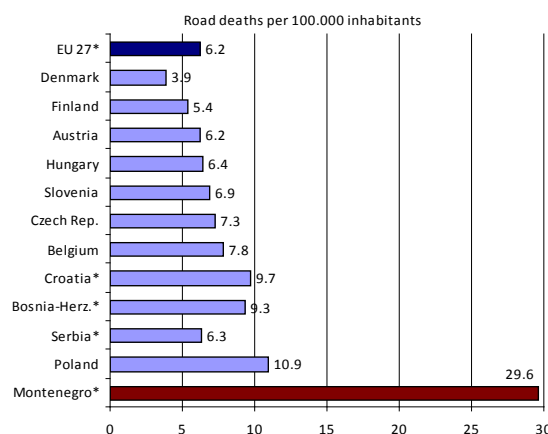


Fig. 4 Fatalities per 100,000 head of population (2010/2011)

Table 3 Traffic accidents and casualties on Montenegrin roads

Year	Accidents		Killed		Injured	
	Total	2000=100	Total	2000=100	Total	2000=100
2000	5597	100	81	100	1933	100
2001	5275	94.2	105	129.6	1957	101.2
2002	5503	98.3	81	100	1834	94.8
2003	5094	91.0	84	103.7	1702	88.0
2004	5377	96.0	91	112.3	1750	90.5
2005	6192	110.6	95	117.3	1942	100.4
2006	7185	128.4	85	104.9	2257	116.7
2007	8882	158.7	122	150.6	2796	144.6
2008	10170	181.7	111	137.0	2473	127.9
2009	10112	180.7	100	123.4	2542	131.5
2010	9138	163.2	95	117.3	2099	108.5
2011	8519	152.2	58	71.6	2075	107.3
2012	8103	144.7	46	56.8	1722	89.1

Number of fatalities per 10,000 registered vehicles is also higher comparing to other countries. However, there is a matter of vehicles from foreign countries in accidents on Montenegro's roads during the tourist season which are not included in the number of 10,000. Considering that fact, this rate (in terms of fatalities per 10,000 registered vehicles) is at same high as neighbor countries (Fig. 5).

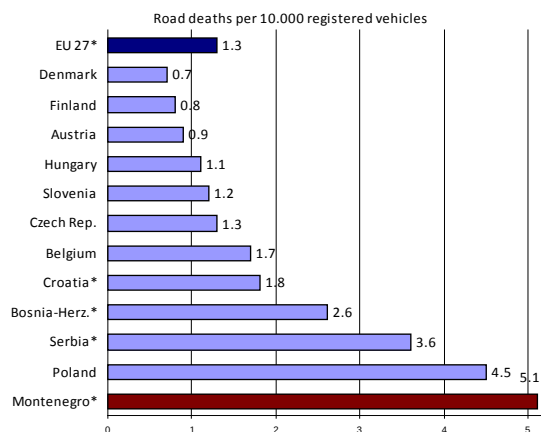


Fig. 5 Fatalities per 10,000 registered vehicles

All indicators show very poor road safety on domestic roads. Years 2007 and 2008 were particularly evil, which was the "price" of uncontrolled growth of motorization (in precedent years) and inadequate road infrastructure that couldn't "bare" an increasing traffic volume. The highest density of fatalities is found on main north-south route Border with Serbia – Bijelo Polje – Podgorica – Cetinje – Budva and Podgorica city zone.

According to WHO 2013 (World Health Organization), over one third of all road deaths in Montenegro is among drivers (34%), /1/. High mortality rate have both occupants and pedestrians, over 20% for each group (see Fig. 6).

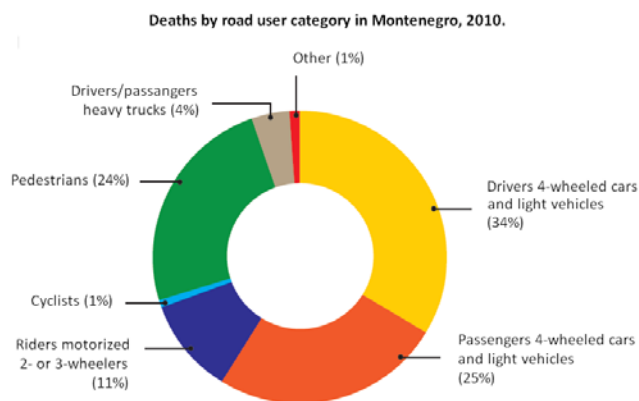


Fig. 6 Fatalities per 10,000 registered vehicles

3. Contrameasures

In May 2011, the United Nations launched a Decade of Action for Road Safety. The goal of the Decade (2011–2020) is to stabilize and reduce the increasing trend in road traffic fatalities, saving an estimated 5 million lives over the period. This report builds on the 2009 report, and provides additional data in a number of important areas. It is supported by a Global Plan for Road Safety. As a response, several countries released or updated in 2011 their national road safety strategies, /5/.

Although EU statistics clearly shows the progress that has been made over the last 10 years, road traffic safety performance in Montenegro is very poor.

Having traffic safety figures so bad, efforts have been made in recent years to address this issue. In 2010 National Coordination Board was established in Montenegro to monitor road safety parameters. In addition, government adopted Strategy for improvement of road traffic safety. Main goal of this strategy is to reduce number of fatalities by 30% and injuries by 20% before 2014 (compared to 2007). Long-term goal is to reduce these figures by 50% and 30% respectively by 2019, compared to the same year. Sadly, the growing interest in reducing road traffic risk is not accompanied with active road safety policies. Proposed measures are inadequate and insufficient – partly because addressing the situation properly requires considerable investments.

4. Conclusion

Over the last decade nearly all EU countries record a decrease in number of traffic casualties year after year. However, in the same period Montenegro's figures generally point in opposite direction – until 2007 – 2008 trend is towards an incline (with small exceptions) and declines only in last 2 – 3 years.

Dynamic growth of motorisation over the last 5-6 years took the government by surprise. With the road infrastructure unsuitable for the growing needs, a largely differentiated fleet of cars, difficulties with effective traffic enforcement and too few effective preventative schemes, the effects of growing motorisation have turned into a painful experience. In 2011 and 2012 Montenegro reduced number of road accidents and fatalities. The percentage of fatalities that occurred in crashes in 2012 was reduced by 52% compared with 2010 and by 62% compared with 2007. Major mortality rate is among drivers – about 34% of all road deaths.

Even though some improvements were made (government adopted Strategy for improvement of road traffic safety), the overall risk indicators in Montenegro remain above the EU average, not showing a decrease in their trend and a lot of work is yet to be done.

5. References

- /1/ World Health Organization (WHO) – Global status report on road safety, 2013
- /2/ MONSTAT, Traffic in Montenegro 2005–2010, Podgorica, 2011
- /3/ COWIS A/S, World Bank – Road Safety Survey Montenegro, Final Report, 2008
- /4/ Pajkovic, V., Grdinic, M., Causes and effects of road traffic accidents in Montenegro (*in Serbian*), Zlatibor, Serbia, 2014
- /5/ European Commission, Directorate General for Mobility and Transport – Road safety evolution in EU, 2012
- /6/ Trends in the Transport Sector 1970–2010, ITF/OECD, 2012
- /7/ IRTAD Road Safety Annual Report 2012, ITF/OECD, 2013
- /8/ European Commission – EU Transport in figures, Statistical pocketbook, 2012
- /9/ Pajkovic, V., Grdinic M., An analysis of young driver accidents in road traffic using in-depth crash investigation data, DEMI 2013, Banja Luka, 2013

DYNAMIC MODEL OF USING POWERED LITHIUM-ION BATTERIES FOR EV / HEV APPLICATIONS

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Abstract: The work presents a simple and easy to use dynamic model for the work of the lithium-ion battery type LiFeYPO4. The dynamics model of charging and discharging of the battery is validated experimentally with a traction battery used in EV / HEV. An interesting feature of this model is the simplicity for extracting of the dynamic parameters of technical specifications of the battery. Only two points on the curve for the discharge of the battery in the steady state are required to obtain the necessary parameters. The model of the battery is included in the simulation using the LabJack U12 in the programming environment LabVIEW2012 for EV / HEV applications. The results show that the model can accurately represent the dynamic behavior of the battery during use of EV / HEV vehicles.

KEYWORDS: *Dynamic model of a lithium-ion battery; Electric vehicles – EV; Hybrid electric vehicles – HEV; State of charge of the battery - SOC .*

1. Introduction

The main element of the electric vehicles (EV), as well as most hybrid electric systems generally is the battery. This element stores a huge amount of energy that needs to be released when required. The battery allows for additional charging from regenerative braking in EV / HEV. .

Battery management system (BMS) has to ensure effective state of charge (SOC) of the battery. To achieve this, the designer of BMS must have a detailed simulation of the system control unit of EV / HEV, including a detailed model of the charge / discharge of the battery. The literature describes essentially three types of models of the battery , in particular: experimental , and the electrochemical reference circuit [2,3] . Experimental and electrochemical models are not well suited to represent the dynamics of the battery cells for the purpose of assessments of the state of charge. Based on the circuit patterns may be utilized to represent the electrical characteristics of the batteries. Developed is an equation for describing the electrochemical behavior of the battery in respect of direct voltage terminal, the voltage of the open circuit, the internal resistance, the current of the discharge and charge level [1]. This model is applied for dilution and charging. A modified version of this model was used in [4]. This modification is based on the use of the polarization of the voltage instead of the polarization of the impedance in order to eliminate the problem of the algebraic loop. This model uses only the SOC of the battery representing the behavior of the voltage as a state variable. This applies to steady state (constant current) this model produces inaccurate results when the state of the current range.

2. Purpose of work

The purpose of this work is to present a simple dynamic model of battery life, which can be applied to variable charge / discharge or changes to current, as in EV / HEV. The work is organized as follows: Section 3 shows a simplified model developed for high-power lithium ion batteries LiFeYPO4. Section 4 presents the model parameters and the procedure for their extraction from the graph of dilution manufacturers [5]. Section 5 presents the results of experimental validation of the model and 6 conclusions.

3. Dynamic model of a lithium-ion battery LiFeYPO4

3.1 Model of discharging

Fig. 1 shows a typical characteristic of the battery discharge. The proposed dynamic model is similar to the model [1], but can be presented in exactly the dynamics of the voltage when the current is different and account the open circuit voltage (OCV) as a function of SOC.

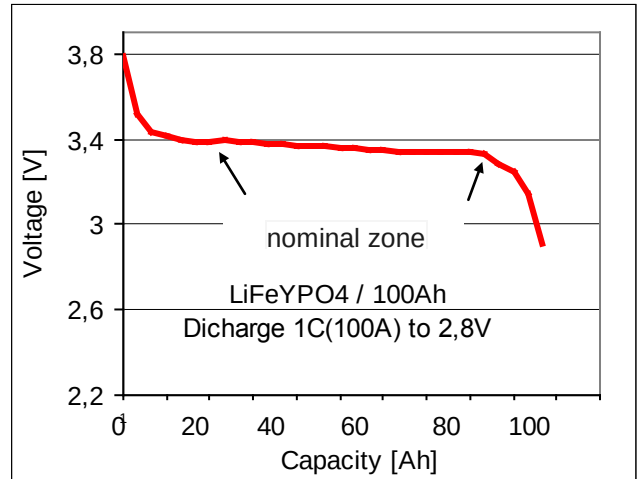


Figure 1. Typical dilution curve of lithium-ion battery LiFeYPO4

The term on the polarization voltage is added to represent better the behavior of OCV. In contrast to [1], where the formula for calculating the voltage to apply to all types of batteries, the battery voltage in this case is only calculated in the nominal area of the formula:

$$V_{batt} = E_0 - K \frac{C}{C - it} \cdot it - R_i - K \frac{C}{C - it} \cdot i^* \quad (1)$$

where:

V_{batt} = battery voltage (V);

E_0 = constant voltage of the battery (V);

K = polarization constant (V = (Ah)) or polarization resistance (Ω);

C = battery capacity (Ah);

$it = \int idt$ = actual battery charging (Ah);

R = internal resistance (Ω);

i = current of the battery (A);

i^* = filtered current (A).

Feature of this model is the use of filtered current (i^*) passing through the polarization resistance [5]. In fact, experimental results show that the dynamic behavior slows down voltage for the reaction step of the current. This filtered current solves the problem of algebraic contour due simulation to electrical systems in Labview. Finally, OCV varies linearly with SOC.

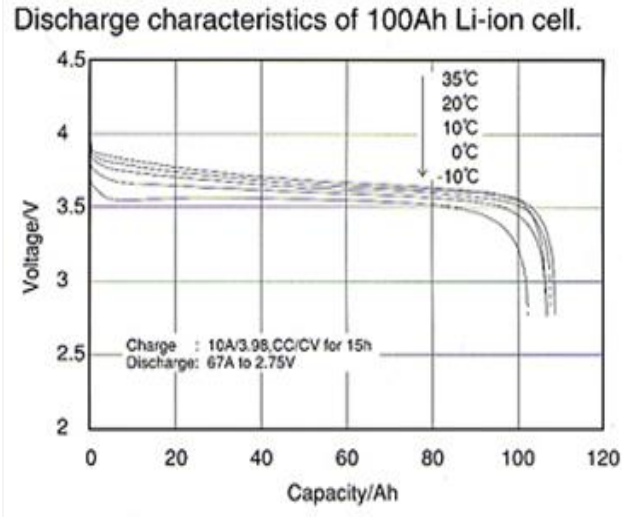


Fig.2. Dilution curve at different temperatures lithium-ion battery LiFeYPO₄

The nominal area of the formula (1) is linear for lithium-ion batteries LiFeYPO₄, as shown in the graph of Figure 2. discharge curves taken from the manufacturer. [5]

3.2 Model of charging

The charging voltage at nominal zone is calculated pa formula:

$$V_{batt} = E_0 - K \frac{C}{it - 0.1.C} . i^* - K \frac{C}{C - it} . it \quad (2)$$

Generalized model of a lithium-ion battery from u-know (1) and (2) in nominal area will be:

$$\begin{aligned} \text{Discharge : } V_{batt} &= E_0 - R . i - K \frac{Q}{Q - it} . it . (it + i^*) \\ \text{Charge: } V_{batt} &= E_0 - R . i - K \frac{Q}{it - 0.1.Q} . i^* - K \frac{Q}{Q - it} . it \end{aligned} \quad (3)$$

3.3. Estimates of the model

The proposed model is based on specific assumptions and restrictions:

- The internal resistance is supposed to be constant during charge and discharge cycle, and do not varies depending on the current amplitude.
- The model only applies to batteries type LiFeYPO₄.
- The parameters of the model are derived from discharge characteristics and shall be supposed to be the same when charging.
- Battery capacity does not change the amplitude of the current (no effect Phuket).
- The temperature no effect on behavior of the model.
- No self-discharge of the battery.
- The battery has no memory effect.

3.4. Limitations of the model

- The minimum unladen battery voltage is 0 V and the maximum battery voltage 2 E₀.
- The minimum battery capacity is 0 Ah and the maximum capacity C. Therefore, the maximum SOC can not be greater than 100% if the battery is recharged.

4. Extraction (sample) of parameters

An important characteristic of the proposed model is the simplicity with which the derived dynamic model parameters. In fact, it is not necessary to take the experimental data of the battery, in order to extract the parameters, if the manufacturer is given the discharge curve. [5] Only two points of the nominal area of the dilution curve at steady state are necessary to obtain the parameters. The manufacturers of the battery provide specifications of the battery data, including "Specifications of the discharge curve" (Fig. 2), where it is possible to derive the fully charged voltage (V_{full}) battery, the voltage at the beginning and end of the nominal area (C_{nom}, V_{nom}) (when the voltage begins to fall sharply exponent) and maximum capacity (C). Also, the internal resistance (R) is generally given.. Only two of these three points is possible solution using equations (1,2,3). The curve of the manufacturer is usually supplied with a constant current (equal to 0,2 C). Fully charged battery voltage, the extracted charge is 0 (it = 0) and the filtered current (i *) is 0, because the current step A has just begun:

$$V_{full} = E_0 - R . i + A \quad (4)$$

In nominal rated voltage zone is given by:

$$V_{nom} = E_0 - K \frac{C}{C - C_{nom}} . (C_{nom} + i) - R . i \quad (5)$$

When C = C_{nom} (when the cells of the battery are new).

$$V_{nom} = E_0 - R . i \quad (6)$$

Therefore, in this type of battery nominal voltage V_{nom} depends on the internal resistance R and current flow i. The time constant of the filtered current (i *) is not given in the technical data from the manufacturer but only experimental data. The test can provide this information. However, the experimental data show a time constant of 30 seconds for this battery. Obviously, these parameters are approximations and the level of accuracy of the model depends on the accuracy of the points derived from the curve. Parameters of the model of cells of this type of lithium-ion batteries are shown in Table 1.

Table 1. Parameters of lithium-ion cells

Type Li-ion batteries	LiFeYPO ₄
Parameters	3,65V/100Ah
$E_0(V)$	3,659
$R(W)$	0.06
$K(W \text{ from } V/(Ah))$	0.047
$A(V)$	0.33
$B(Ah)^{-1}$	26

5. Confirmation Model

5.1. Confirmation of steady state

The proposed model was tested at steady state to play "face area" in Figure 1. provided by the manufacturer of the "Typical discharge curves" (Fig. 2).

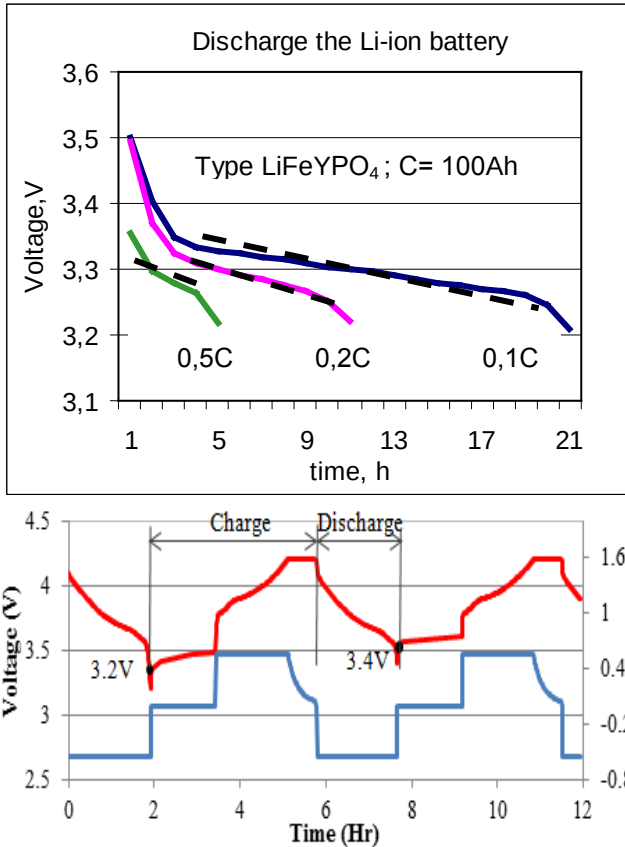


Figure 4. Simulation of discharging the battery type LiFeYPO₄ with discharge current of 0.5 C, 0.2 C and 0.1 C

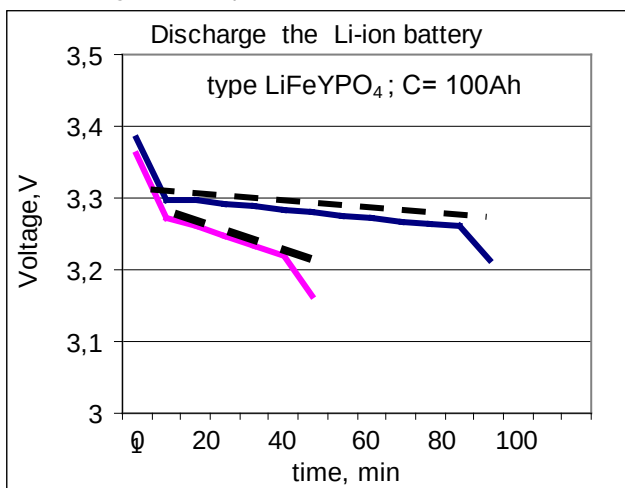


Fig.5. Simulation of discharging the battery type LiFeYPO₄ from the data table of the discharging current 2C and C

Those contours do not represent the dynamic performance of the battery and discharging curves at constant current i of dilution capacity C . Experimental studies are carried out on cell battery pack in order to prove the validity of the model (Figs 4 and 5 and table 1) battery type LiFeYPO₄. Fig. 4 shows the simulation results imposed into the data from the experimental dilution curve. The first graph shows the voltage curve - time for 0,1 C discharge current, the second graph - current 0,2 C and the third - for 0,5 C discharge current. Fig. 5 shows the simulation results of (6) on the nominal area of the curve with 1C and 2C discharge current. With a black dotted line, the results of the simulation - it should be noted that the simulated sections coincide very well with the actual curves in almost 95% of the discharge, regardless of the amplitude of current discharge.

That is because this type of battery having a perfectly flat dilution curve in the nominal area. Cycles of charging and discharging of the battery should not leave the face area because the battery quickly damage from overcharging or over dilution.

5.2 Confirmation of the dynamic behavior

Fig. 6. Simulation of the dynamic behavior of the battery type LiFeYPO₄

The dynamic behavior of a battery is tested by discharging and charging the cell at various levels. A fully charged cell battery 3,9 V to dilute / load to border tensions randomly to simulate real work . The experiments were made with a standard program LabVIEW2012 by a recording device and controlled charging current . Fig . 6 shows two cycles of discharge / charge the Li-Ion battery. Black lines are presented simulation results in formula (3) . The results show that the model is accurate to within 5 %.

6. Conclusion

This experimental validation of the model showed that, even if the model parameters are derived from the steady state of the discharge curve (current discharge is constant) taken from the manufacturer, it is possible to accurately simulate (error of 5%) the dynamic behavior of the voltage battery charge and discharge processes. The new simplified dynamic model of the battery type LiFeYPO₄ allows adequate representation of the actual behavior of the battery based on the extraction of only two points of the discharge curve taken from the battery manufacturer. This model can be used in the development of algorithms and software for the evaluation of the state of charge (SOC) in the development of a system for battery management.

Literature

- [1] Shepherd, C. M., Design of Primary and Secondary Cells - Part describing battery discharge, Journal of ociety, Volume 112, July 1965, pp 657-664.
- [2] Durr, Matthias; Cruden, Andrew; Gair, Sinclair; Mc- Donald, J.R, Dynamic model of a lead acid battery for use in a domestic fuel cell system, Journal of Power Sources, Volume 161, no 2, Oct 27, 2006, pp. 1400-1411.
- [3] Kuhn, E.; Forgez, C.; Lagonotte, P.; Friedrich, G., Modelling Ni-MH battery using Cauer and Foster structures, Journal of Power Sources, v 158, no 2 SPEC. ISS., Aug 25, 2006, pp. 1490-1497.
- [4] Olivier Tremblay1, Louis-A. Dessaint, Experimental Validation of a Battery Dynamic Model for EV Applications, World Electric Vehicle Journal Vol. 3 - ISSN 2032-6653 - © 2009 AVERE
- [5] www.ev-power.eu/.../WB-LYP100AHA-LiFeYPO4-3-2V-100Ah.html

COMPARATIVE ANALYSIS OF PMAC MOTORS FOR EV AND HEV APPLICATIONS

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Abstract: In current work is made comparison between the differences in structure methods of propulsion and price of two types of motors with permanent magnets and AC drive (PMAC). PMAC is common name of electric motors - permanent magnets synchronous motor (PMSM) and brushless permanent magnet motor (BLDC). On the basis of comparative studies is selected and tested construction and propulsion of low-cost BLDC motor, suitable for hybrid transmission of HEV.

KEYWORDS: PMAC - Electric motor with permanent magnets and AC propulsion; BLDC - Brushless DC motor with permanent magnets; PMSM - Permanent magnets synchronous motor; EV - Electric vehicles ; HEV- Hybrid electric vehicles; BEMF- Back electromagnetic force.

1. Introduction

The great interest in the implementation of environmentally friendly vehicles require the development and testing of increasingly sophisticated structures traction motors with powerful permanent magnets, the composition of which has exotic rare transition metals (lanthanides). Most frequently in the production of electric cars using synchronous induction motors with permanent magnets (PMSM) [1]. Some companies produce cheaper brushless DC permanent magnet motors (BLDC), suitable for smaller EV / HEV applications [1,3]. Both motors are lightweight, powerful, have regenerative braking system - this is the process by which the motor is used as a generator to refuel the battery when the car stops. These motors are known collectively as the electric motors with permanent magnets and AC drive (electric PMAC) [3]. The main characteristics, advantages and disadvantages are discussed below.

2. Purpose of work

In this work are analyzed and compared the characteristics of the latest PMAC motors used in today's electric (EV) and hybrid vehicles (HEV). Based on the analysis is selected and tested low-cost BLDC motor, suitable for deployment in a hybrid transmission for HEV applications. The work is structured in five parts. The first is a brief analysis of the structure , the basic principles of power and producing the torque of these motors , in the second part we examine the benefits and disadvantages of PMAC Electric and differences between the two species. The third part is devoted to the analysis and testing of selected BLDC motor specifically for HEV application. The fourth part presents experimental studies of selected electric motor and a fifth are locked.

3. Construction and principles for propulsion of PMAC electric motors

There are two basic constructions of the PMAC motor - a structure which is based on the method of mounting of the magnets on the rotor and on the waveform of the back electromagnetic force (BEMF). If the magnets are mounted on the surface of the rotor of the motor, PMAC motor is called a surface-mounted permanent magnets. If the magnets are mounted within the rotor, then the PMAC motor is called internally fitted with permanent magnets. Management trapezoidal waveform BEMF characteristic of BLDC motors, and when the waveform is sinusoidal, the motor is PMSM. The type of construction is either cylindrical (fig.3.1.) Or type "pancake" (fig.3.2.)

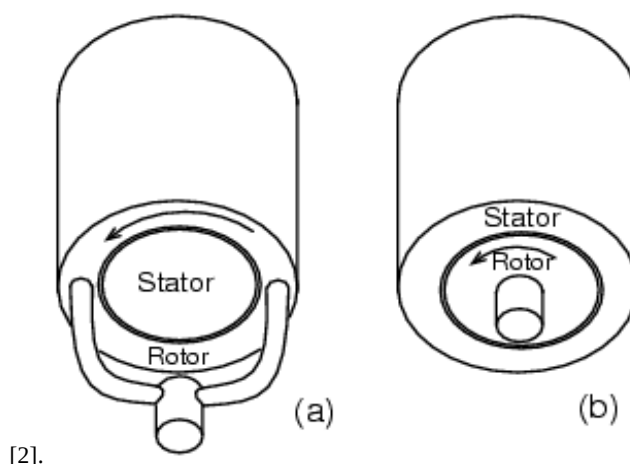


Fig. 3.1. Cylindrical structure PMAC motors
(a) External rotor, (b) internal rotor

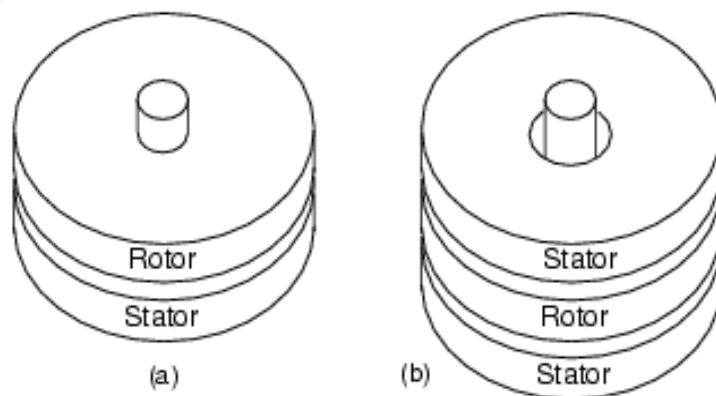


fig.3.2. Construction type "pancake" motors of RMAS
(a) a single stator (b) a double stator

From fig . 3.2 . shows that the highest torque motor must have a "pancake " dual stator - fig.3.2 (b). Engines with a stator on one side of the rotor shown in fig . 3.2 (a) have found wide application in floppy drives on computers. In this type of electric motor , the direction of magnetic flux is axial , i.e. parallel to the axis of rotation . From the above figures it is clear that the structure type "pancake " dual stator shown in fig . 3.2. (B) is the light with the highest torque and therefore is suitable for HEV applications

3.1. Operative principles of drive for PMAC electric motors

One category PMAC motors - BLDC electric motors can be operated with a closed system that is very simple and cheap, because the control variables are readily available at all times

during operation of the motor movement. PMSM electric motor have options to control the drive in open loop, but this control is not as simple and easy as the BLDC and is similar to drive induction motors. For PMSM drives need a advanced control techniques, such as vector control and direct torque control, that makes PMSM motor more expensive [3]. In contrast to PMSM motor which requires constant monitoring of the position of the rotor, BLDC motor with trapezoidal shaped BEMF requires only monitoring every 60 electrical degrees of the period for switching the phase currents. As a result, necessary six switching points per electrical cycle. In general, in each switching point, the switching cycles of change. In this way, it is not necessary to have a position of a sensor with a high resolution as an absolute or incremental encoder or resolver. In this case, a very simple and cheapest (cost <\$ 1) sensor with Hall effect will be enough appropriate. This makes the BLDC motor cheaper than PMSM [4]. During these intervals, switching, however, found waves of torque, creating uneven at low revs and noise during operation of BLDC motor.

3.2. Comparison of torque moment of electric motors PMSM and BLDC

Electric motor BLDC have high torque density at low and medium speed, but is not suitable for continuous operation at high speed, because of its limited capability of weakening the flow. Also, the BLDC trapezoidal shape of the current wave, the torque pulsation is performed in the sixth harmonic of the fundamental frequency. Equations written below show the difference in the density of torque between BLDC and PMSM electric motor in the region of constant torque (PMSM has a dominance in the region, weakening the flow over the motor BLDC). Suppose that I_{ps} and I_p are the peak values of the stator currents in electric motors PMSM and BLDC, respectively, the rms value of these currents are:

$$I_{xw} = \frac{I_{ps}}{\sqrt{2}} \quad (3.1.)$$

$$I_d = \frac{I_p \sqrt{2}}{\sqrt{3}} \quad (3.2.)$$

Equating the losses in the copper and the substitution of the currents in terms of their peak flow gives:

$$3I_{xy}^2 R_s = 3I_d^2 R_s \quad (3.3.)$$

Consequently,

$$I_p = \frac{\sqrt{3}}{2} I_{ps} \quad (3.4.)$$

Proportion of torque to the BLDC and PMSM motors is derived from these relationships, as follows:

$$\frac{BLDC}{PMSM} = \frac{(2xE_p x I_p) / \omega}{\left[3x \frac{E_p}{\sqrt{2}} x \frac{I_{ps}}{\sqrt{2}} \right] / \omega} = 1,154 \quad (3.5.)$$

The above result indicates that the BLDC motor is about 15.5% more torque than a PMSM in the constant region of the torque. [5] In BLDC under ideal switching, the current is conducted through

120 electrical degrees, with a peak centered BEMF as shown in fig. 3.3. with Hall sensors.

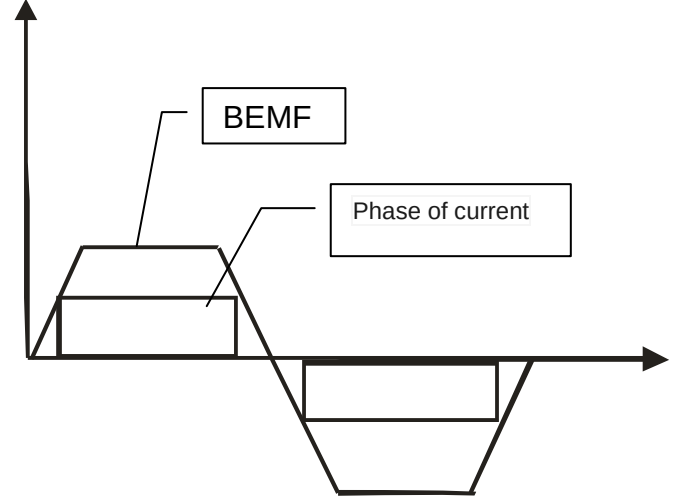


Fig. 3.3. Ideal operation of BLDC motor.

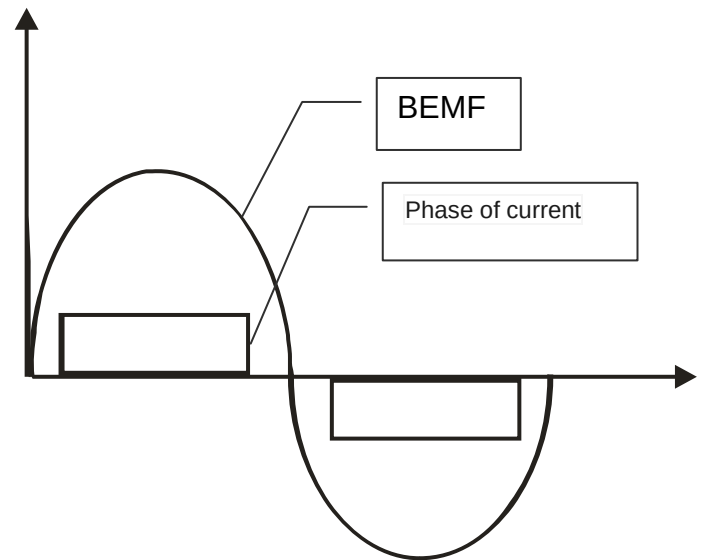


Fig. 3.4. BLDC is controlled like PMSM motor.

BLDC motor may be used as a synchronous motor PMSM as shown in fig. 3.4., but with a complex sinusoidal commutation, for example, with an encoder. [9] Consequently, BLDC is optimized to be managed by the trapezoidal waveform, and is optimized for PMSM control with sinusoidal waveform. BLDC provides commutation electronically and has a closed loop system. Variable frequency of alternating current (AC) drive (inverter) may be used by the same engine PMAC can perform the functions of a BLDC motor in a closed loop (with Hall sensors) and the functions of alternating current AC synchronous motor PMSM in open loop when the engine does not conduct feedback to the controller (for example, when switching is performed with an optical encoder). As a result, if the torque pulsations are not very important, the simple trapezoidal current control scheme (type BLDC), instead of a complex sinusoidal current control scheme (type PMSM), can not be stable, cost-effective and very good solution to control the speed and torque of the engine HEV applications.

4. Advantages and disadvantages of electric motors PMAC

PMAC Compared with conventional motors, PMAC motors have many advantages:

- PMAC electric motors are highly efficient engines. PMSM and BLDC are considered the most efficient of all electric motors. There is a lack of copper coil or a mechanical coupling of the rotor by a collector and brushes. Instead, the permanent magnets of the rotor are used for generating a constant magnetic field of the rotor. These magnets do not consume almost no power, so copper losses are negligible level rotor unlike AC induction and synchronous motors. Also, friction is low and the durability is higher, since no mechanical collector and brushes to wear, in contrast to the direct current brush motors. All these characteristics of electric motors PMAC put them first on the category of high efficiency [6] and makes them very suitable for EV and HEV applications.
- Recent advances in production of permanent magnets with high energy density used in the composition of rare-earth metals, such as in the sintered alloys, samarium-cobalt or neodymium-iron-boron (SmSo; NdFeB), have allowed the achievement of very high magnetic induction motors PMAC . These magnets ensure the provision of high torque and allow the engine to be built smaller and lighter. [6]
- In electric motors PMAC will located in the rotor circuit , which decreases heat and electrical losses. The heat is produced only on the stator , which is more easily cooled by the rotor , because the stator is usually static, and is located on the outer side of the electric motor . [6] PMAC have low maintenance costs, durability and reliability. Brushless and mechanical switches, regular maintenance is significantly reduced and risks such as sparks in explosive or corrosive environments are eliminated. The long life of the motor is based primarily on the quality of the insulation of the windings and bearings (as with other electric motors) , and the lifetime of the magnets [6].
- There is no operating noise generated by switching, because this is achieved electronically rather than mechanically. The switching frequency of the converter when PMSM is sufficiently high so that the harmonics of the noise can not be heard. [6] Because of the trapezoidal waveform of BLDC motors BEMF when there is some noise from the harmonics, but it is very weak and can not be ignored, especially in HEV applications.

PMAC electric motors also have some disadvantages entailed just like any other electrical machines and more specific:

- The cost of permanent magnets is the most important question for both PMAC motor . Permanent magnets rare earth elements such as samarium - cobalt and neodymium - iron -boron are particularly expensive . Magnets neodymium - boron- iron are the most powerful , but also the most expensive. If the initial cost is a major problem in some applications that will be used PMAC motors, then the price of magnets with higher energy density does not allow their use in these applications [6]. For HEV applications the main problem is the compactness and weight of the bike , so electric motors with permanent magnets with high energy density are best suited for these applications .

- Many large opposing magneto-drivers and high temperature can demagnetize the magnets. Although critical of the demagnetization effect is different for each magnetic material should be taken further measures to cool the motor, especially if it is built with compact design (for example, type "pancake") [2,6].
- For surface mounted magnets PMAC motors operate at high speed is limited or not possible due to the mechanical construction of the rotor. The rotor is not suitable to deal with high centrifugal forces at high speed when the magnets are glued on it . This type of installation is not strong enough and does not guarantee the integrity of the magnets , especially in high-speed compact engines. On the other hand , mounted on an internal magnets, the rotors of the PMAC motor are able to move at high speed without a problem in terms of the rotor, because the magnets are mounted within the rotor , but the degaussing is still an important factor in these types of motors [6]
- Since there is a constant energy of the rotor due to permanent magnets , PMAC motors represent a major risk event of a short circuit in winding or damage to the inverter. If a short circuit occurs in the inverter during operation of the motor, the rotor will constantly induced electromotive force in a coil shorted , causing a very large electricity and heat engine. This leads to large reverse torque which tends to block the rotor. For automotive applications , the risk of blocking is not acceptable and must take precautions to protect against short circuit [6]. Fig . 4.1. shows the equivalent circuit for three-phase power transmission from the inverter to the motor PMAC.

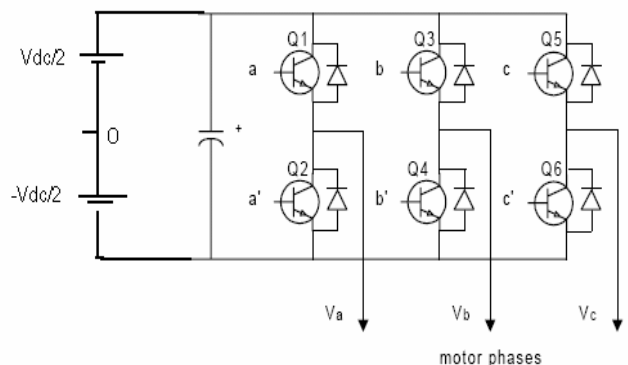


Figure 4.1. Circuit for power transmission with three-phase voltage - inverter (VSI)

The structure of a typical inverter - a three-phase voltage source is shown in fig . 4.1. V_a , V_b and V_c are the output voltages applied to the motor windings . Q1 through Q6 are six power transistors that form the output , which are controlled by one " , b , B ' , c and C ' . For AC engine management when the upper transistor switch is turned on, ie , when A, B or C is 1, the corresponding lower transistor is switched off , ie corresponding to "b" or B "is 0.che This means setting the upper line of the switch to turn off and turn on the lower line key and vice versa. exclusion of the states of the upper transistors Q1, Q3 and Q5, or equivalent the states of the A, B and C , are sufficient for an assessment of the output voltage.

5. Selection of brushless electric motor (BLDC) for HEV applications

From the above analysis of the structure, propulsion, advantages and disadvantages of PMAC motors, we conclude that application to power hybrid vehicles in an urban environment, the most appropriate type BLDC motor "pancake" with double stator. We

have selected engine type HPM10KW/120V, production of "Golden motor."

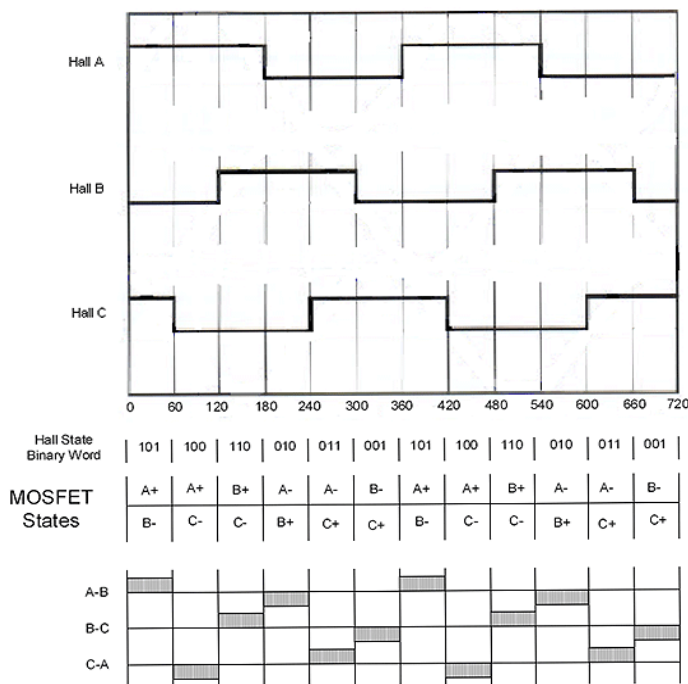


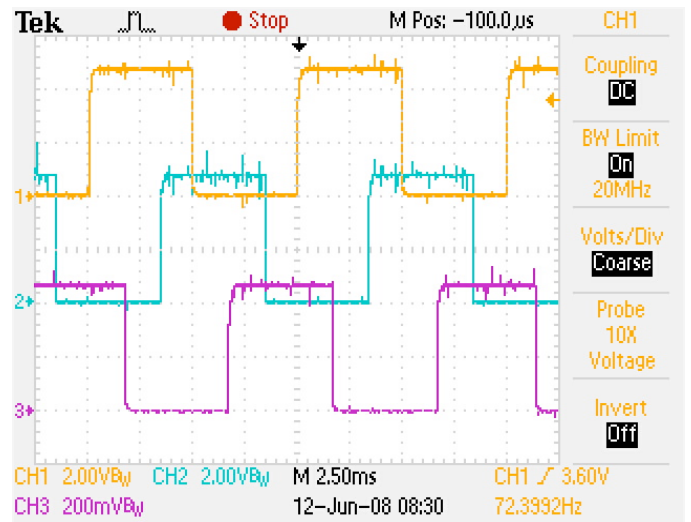
Figure 5.1. Driven by commutation of voltage switching sensors with "Hall" effect .

Each phase BLDC powered by a digital controller in appropriate sequence. Energy is synchronized with the position of the rotor to produce a constant torque, therefore, it is important to know the position of the rotor in order to understand which winding will the Subscriber after energizing sequence. This motor is driven by a system of the Hall sensors as described above, controlling the rotor position [3,4]. For example, in fig. 5.1. Hall-A is aligned with $E_a = E_a - E_b$ etc. etc. This means that the output of each sensor with a Hall effect actually leads to a zero crossing of the phase of each BEMF by 30 electrical degrees.

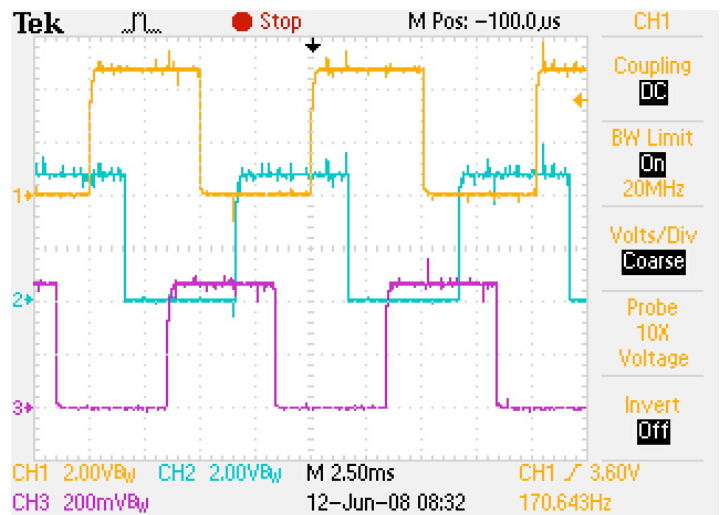
The position information is then used by the controller to decide to activate the inverter switches. Generally, three sensors with Hall effect are used for the three-phase motor (will be referred to as Hall A, B Hall and Hall C., with each 120 ° delay with respect to the previous sensor) to determine the position of the magnetic field of the rotor. When the magnetic poles of rotor pass near sensors with Hall effect, high or low signal is generated when N (North) or S (south) poles pass near the sensors. In general, when the north pole signal corresponds to a "1" and when the south pole of the "0" [5]. Graph of the Hall effect with 120 ° angle sensors divided into operation shown in Figure 5.1. This table represents the state of the high-side and low-side MOSFET transistors of the amplifiers of the half bridge for all three phases during commutation trapezoidal. [4] Sensors rely on speed, position, etc. and send them to the controller that corrects these indications to achieve the desired parameters.

6. Experimental tests of BLDC motor

Experimental verification is carried out on trapezoidal commutation, whether it is possible to control the BLDC motor with trapezoidal commutation sensors using Hall effect. Experimental waveforms of Hall signals as well three in the clockwise (CW), and counterclockwise (CCW) direction of rotation of the motor are shown in Figure 6.1. The rolling direction is viewed on the motor shaft. Series of signals are Hall Hall A-Hall B-Hall C in CW and Hall B-Hall C-Hall A in the direction CCW.



(a) CW direction



(b) CCW direction

Fig. 6.1. Measured signals Hall in CW and CCW direction of 1500r/min (CH1: Hall A, CH2: Hall B, CH3: Hall C) (Vertical: 2V/div, Time: 5ms/div)

Trapezoidal propulsion based sensors with Hall effect is six steps of current and is shown in Figure 6.2.

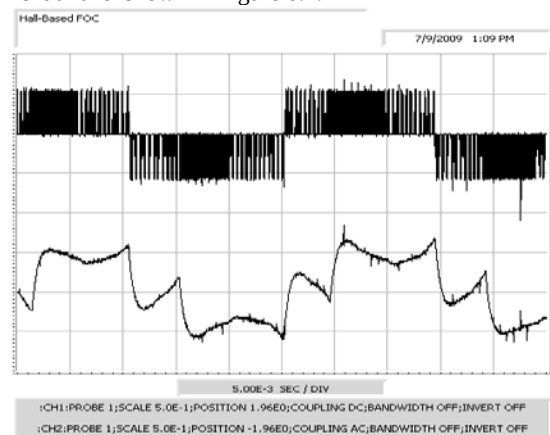


Fig. 6.2. Connection between motor online to line voltage (peak: 25V/div) and line current (bottom: 0.5A/div) six-step commutation

It can be seen that the sensor-based Hall effect trapezoidal drive six-step current, as shown in Figure 6.2. Is not an ideal sinusoid, which results in certain ripple during commutation.

7. Conclusion

Trapezoidal commutation generates rotating waves (pulses) at low speed and relatively effective only in the range of high speeds. However, this method is very popular because of the simplicity of its control algorithm. It uses six successive stages by means of three sensors with Hall effect, in order to obtain information about the position of the rotor. It is very effective in controlling the engine speed, but suffers from a torque ripple during commutation, particularly at low speeds. Therefore, this scheme is the most popular low-budget class applications requiring simple operation and closed loop. The disadvantage is that there is a significant moment of pulses generated by the nonlinearity of the switching, because only two motor windings is current at any given time. Nonlinearities generate noise and vibration. When I used to work at a relatively high speed, 1200 switching provides minimal torque ripple, which is perfectly acceptable for hybrid drive in urban HEV applications.

Literature

1. *Electric motor: Permanent-magnet-motors*, www.britannica.com/ebc/article-45836
2. http://www.allaboutcircuits.com/vol_2/chpt_13/6.html
3. [12]. P. Pillay and R. Krishnan, "Modeling, Simulation and Analysis of a Permanent Magnet Brushless DC motor drive part II: The brushless DC motor drive," *IEEE Transactions on Industry application*, Vol.25, May/Apr 1989.
4. N. Chaudhary, Al. Mishra, *Hall Effect and Its Application in the Design & Operation of Electronically Controlled Brushless DC Motors*, IJAIEM, Volume 1, Issue 2, October 2012, 201-207 (ISSN 2319 – 4847)
5. P. Pillay, "Modeling simulation and analysis of permanent magnet synchronous and brushless DC motor drives." Ph.D. dissertation, Virginia Polytechnic Institute and State University, Blacksburg, VI, 1987.
6. J. Luukko, "Direct torque control of permanent magnet synchronous machines - analysis and implementation." Ph.D. dissertation, Lappeenranta University of Technology, Lappeenranta, Finland, 2000.
7. P. Yedamale, "Brushless DC (BLDC) Motor Fundamentals," Application Note 885, Microchip Technology Inc., Chandler, AZ, 2003.
8. <http://www.magnetlab.com/uploads/4c51d9ba6fe5a.pdf>
9. <http://www.kves.utc.sk/kvesnew/dokumenty/%C5%A1ep/DTC-Ozturk.pdf>

POSSIBILITIES FOR OPTIMIZING MAINTENANCE OF MILITARY VEHICLES ON THE RESULTS OF TRIBOLOGICAL DIAGNOSTICS

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Abstract: Tribological diagnostics is a non-destructive and non-disassembling diagnostic method, that uses lubricating oil as a source of information about processes and changes in mechanical systems, to which it is applied. The paper deals with the mathematical processing, monitoring and analysis of the oil field data obtained from the atomic emission spectrometry in frame of the tribodiagnostic oil tests. The mathematical methods based on a regression analysis and calculations are used in the paper for oil data analysis. The whole assessment procedure and their outcomes serve as identification of a suitable approximation trend. With the same result we are capable of determining in-service operation history as well as giving inputs to maintenance optimisation. Nowadays the system requirements are set up and evaluated in various manners. We would like to keep both preventive and corrective maintenance costs as low as possible. A system design and a maintenance system help to fulfil this task. We propose to use one of the approximations presented in order to track the system operation behaviour.

Keywords: TRIBODIAGNOSTIC, WEAR, OPERATION ASSESSMENT, MAINTENANCE OPTIMISATION

1. Introduction

The growing dependability and operation safety requirements for modern equipment together with the increasing complexity and continuous attempts to reduce operation and maintenance costs might be satisfied among others by the consistent use of modern diagnostic systems. The main task of object technical state diagnostics is not only to find out incurred failures, but also to prevent from the failure occurrence with the help of sensible detection and changes localization in the object structure and in its behaviour changes. A tribotechnical system (TTS), friction in it, wear and lubrication, and especially the outcomes of it are the subjects of our major concern. Regarding the tribotechnical system, the basic information about tribological process, operating and loss variables are provided. Tribology is the science and technology of interacting surfaces in relative motion. The function of a tribotechnical system is to use the system structure to convert input variables (e.g. input torque, input speed, the input type of motion, and the sequence of motions) into technically utilizable output variables (e.g., output torque, output speed, output motion) [1, 2].

The type of interaction occurring primarily depends greatly on the friction state. Thus, when a lubricant is present, the atomic/molecular interaction can be disregarded more often than the mechanical. Friction and wear in a given TTS ultimately depend on the interactions between the elements. The friction state, the effective mechanisms of friction and wear, and the contact state can be used to describe the interactions. The tribologic loads occurring in the real contact areas produce tribologic processes. They subsume the dynamic physical and chemical mechanisms of friction and wear and boundary-layer processes that can be attributed to friction and wear.

Owing to the TTS we have got a lot of diagnostic oil data. In view of tribo-diagnostics this data is considered to be the final outcome. This data can tell us a lot about lubricants / life fluids quality itself as well as about system condition. From the reliability, maintainability and safety point of view we consider such data to be very valuable. We distinguish different methods for oil / life fluids samples analysing. These methods are used to determine physical quality of the sample. Since the system operation, taking the oil samples and the outcomes themselves, are very fuzzy, we later expect to adapt some approaches from the fuzzy logic theory to help.

The procedure and results presented below are based on standard mathematical principles – a regression function and a regression analysis. Later these will be supported by fuzzy logic approaches.

We present results which contribute to general approach when considering both the maintenance procedures and the cost analysis optimisation. From both presumptions we are expecting some costs savings. As for the military point of view we would like to determine remaining “time units” in order to perform the mission.

Following the regression analysis performed beforehand it is possible among others to assess the operating history of an observed vehicle. When analyzing the data we focus on such chemical substances in oil which are somehow interesting for us. These are the products of mechanical processes and wear. The elements originated either in bearings or different parts of kinematic accouplements. We do not take into account any additives. The elements of our primary concern are ferrum, cuprum and lead. It results from the observations and performed analyses that ferrum behaves presumably in the most interesting manner. Therefore we are going into it in a more detailed way.

We do not mention all the results of regression analyses in the paper (especially not for lead and cuprum).

However, after comparing them, we have come to the following conclusions:

- The dependence of cuprum on operating hour (Mh) is not evident so it does not bring us to any common conclusion.
- When dealing with the dependence of lead on operating hour (Mh), there are similarities among all kinds of vehicles, but the multiple correlation coefficient of a tank and infantry fighting vehicle data is too small for a relevant regression function to describe selected data well.
- When dealing with the dependence of ferrum on operating hour, there are also similarities among all kinds of vehicles, but a multiple correlation coefficient is higher. Therefore it is convenient to concentrate only on the dependence of ferrum on Mh.

Oil analysis methods:

Atomic emission spectrometry (AES) is a method that uses arc or spark sources to get the oil sample into the gaseous state and atomize it. As a result of atomic collisions or energy quantum absorption, the electrons of individual atoms are transiting from the ground state to the excited state. During the transition back to the ground state, atoms emit energy that equals the proportion of the energy levels in question in the form of luminous energy. The wavelength of light value is specific for each element [1,2,3,].

2. Objects of diagnostics and diagnostics methods

The assumed objects of diagnostics, i.e. the tank engines T-72M4CZ, TATRA 810 and BMP II have not been ready yet in terms of design to use the ON-LINE system, though in practice similar possibilities for other applications have already existed. It results from the information stated above that we are still supposed to use OFF-LINE engine diagnostics system when sampling lubrication fluid at certain intervals, and using known and optimised special tribodiagnostic methods [4], [5], [6] and [7].

The recognition of a technical state is a basic assumption for making a diagnosis used for determining either operability or non-operability, or for the detection, recognition, distinction, and localization of system parts faults. Although the data on the object condition obtained from a lubrication fluid is available, little importance is attached to it when changing the oil. If the condition of lubrication fluid affected not only evaluation of the object condition, but also modification and optimisation of exchange dates, it would be notably positive in terms of economic optimisation. When evaluating data, the information is transformed many times and provides only estimated reality which might be different from reality itself. That is why the pattern recognition is an important and very complex area of technical diagnostics. Generally the recognition is divided into two groups depending on which methods are used - syntactic or signature. A Parsing/Syntactic Method – is based on recognizing a qualitative way. A word or a symbol string represents the pattern reflecting an object, an event or a process. A Signature Method – is based on recognizing objects, events, or processes with the help of an arranged set of numbers which describe the object characteristics. In diagnostics in many cases there is no exact line between an up state and fault, i.e. there is no mutually explicit representation among points spaces and points classes spaces and corresponding technical states – diagnoses. The failure classes intersect which means that the same magnitudes of measured characteristics might correspond with different diagnoses. If the vagueness in classes distribution is not given by a stochastic character of measured characteristics but by the fact that the exact line among states classes does not exist, it will be later on good to use fuzzy set theory and adequate multi-criteria fuzzy logic. One of the most important information sources might be the results of ferographical analysis (a type, a size, material composition, distribution, morphology, speed of generation, etc.) and particles wear in real time, or lubrication oil degradation got by the methods FTIR, etc. However, it has not been possible to get this information in real time yet. In our case we use the results and information from atomic emission spectrometry. Following this analysis we can obtain the information about the presence of the elements of a specific kind and the amount of elements. However, we cannot identify their origin – e.g. as a result of fatigue, cutting or sliding. Therefore in our further research we try to identify where the elements might come from.

3. Oil field data assessment

Having enough field data obtained from a statistically important set of diagnosed objects is a basic assumption that we will solve this problem successfully (e.g. the engines themselves, etc.). Since the data sets are very extensive, we are not going to introduce them here except for a part/example of ferrum particles found in an infantry fighting vehicle engine. But we deal with dozens of samples taken and analysed at different types of observed engines. In certain aspects we consider the engine in an infantry fighting vehicle II to be a reference object, because the event of a failure type has occurred in it. All tribodiagnostic processes related to the failure occurrence have been recorded.

Technical state diagnostics and engine monitoring includes system approach which deals with sampling, analysis and information utilisation which is important in relation to a mechanical or thermodynamic engine state. Generally it is about monitoring and assessing wearing particles and pollution in life fluids (e.g. hydraulic and engine oils), or metal wearing particles

monitoring, non-metal polluting particles monitoring, products of burning process by high or low temperatures, soft pollutants of organic origin which form oil resin, so called cold sediments, oil and fuels oxidation products, hard-solid pollutants of inorganic origin, dust particles of silicon origin, etc. The monitoring covers a life fluid sample collection and its off-line analysis using easy, standard or special – instrumental methods. The increased forming of metal magnetic wearing particles is usually monitored too, using magnetic detectors with recording and signalization. Using the on-line diagnostics based on a laser particles analyser appears to be a very progressive method. This method enables us to find wearing particles according to a corresponding wearing mechanism (fatigue), adhesion, abrasion, cavitations, corrosion, vibration, combination of the situations mentioned above together with expressing the state, prognosis, trends calculations, etc., supported by intelligent software in the future in real time [3].

Utilisation of regression model

Exploring and analyzing variable dependencies, the values of which are obtained when performing an experiment, is considered to be an important statistical task. In view of their random character, a random vector $X = (X_1, \dots, X_k)$ represents independent variables and a dependent variable is represented by a random variable Y .

When describing and examining the dependence of Y on X , we use a regression analysis, and this dependence is expressed by the following regression function:

$$y = \varphi(\mathbf{x}, \boldsymbol{\beta}) = E(Y | \mathbf{X} = \mathbf{x}), \quad (1)$$

where $\mathbf{x} = (x_1, \dots, x_k)$ vector of independent variables, y is a dependent variable, $\boldsymbol{\beta} = (\beta_1, \dots, \beta_m)$ vector of regression coefficients β_j .

For our data we will look for a regression function in a linear form and we will apply a linear regression model:

$$y = \sum_{j=1}^m \beta_j f_j(\mathbf{x}), \quad (2)$$

where $f_j(\mathbf{x})$ are well-known functions where $\beta_1, \dots, \beta_m$ are not involved.

4. Proposals for system health and condition monitoring based on the results of tribodiagnosics

In the case of taking single oil samples a time line might be possibly not stationary, and before making next calculation it needs to become stationary (non-constant mean value and dispersion); standard transformations do not provide satisfactory results.

The analysis results detected from the oil provide a potential space for the modification of oil exchangeable date considering the number of particles present in the oil before the actual change. The situation is interesting especially with regard to the velocity of their occurrence. A recognized number of particles before the actual change would not necessarily mean a critical number which could threat reliable engine function or cause an accident. However, the exchange date is determined by an oil producer, and the time period in which the exchange is performed might be significantly affected by other characteristics. The presence and the number of particles which occurred in a lubricating system by mechanical processes should be viewed in the future as one of the most important factors in the process of lubrication fluid state assessment.

Following the results it is also necessary to decide on the approximation of real course of particles generation. On the basis of the calculations already made we estimate that the linear regression model will be the most suitable for many reasons. In Table 1 there are single regression analysis models for the observed type of a vehicle.

Table 1: Regression models comparison – outcomes.

Regression function	$y=\beta_1$	$y=\beta_1+\beta_2x$	$y=\beta_1+\beta_2x+\beta_3x^2$
Vehicle type			
Tank	$y=17.945$ $r^2=0$	$y=13.712+0.0949x$ H: $\beta_2=0$ is rejected for $\alpha=0.05$ $r^2=0.3856$	$y=13.816+0.0882x+0.00055x^2$ H: $\beta_3=0$ is not rejected for $\alpha=0.05$ $r^2=0.3859$
APC	$y=24.069$ $r^2=0$	$y=14.099+0.0723x$ H: $\beta_2=0$ is rejected for $\alpha=0.05$ $r^2=0.5022$	$y=10.373+0.1333x+0.0002x^2$ H: $\beta_3=0$ is not rejected for $\alpha=0.0005$ $r^2=0.5474$
T-810	$y=15.604$ $r^2=0$	$y=13.561+0.0282x$ H: $\beta_2=0$ is rejected for $\alpha=0.05$ $r^2=0.3488$	$y=12.9132+0.0525x+0.000079x^2$ H: $\beta_3=0$ is not rejected for $\alpha=0.001$ $r^2=0.378$

It results from the Table that in all the cases it is convenient to consider the regression function in the form $y=\beta_1+\beta_2x$. The regression function $y=\beta_1$ is too simple, and does not reflect the dependence. The regression function $y=\beta_1+\beta_2x+\beta_3x^2$ reflects the dependence better than $y=\beta_1+\beta_2x$, but the coefficients β_3 are statistically unimportant and the growth of a multiple correlation coefficient is not that fast as compared with the regression function value: $y=\beta_1+\beta_2x$.

On the basis of the performed analysis we can say that we are able to assess/observe operating history. Owing to this fact it is possible to plan and verify maintenance actions or other operation of vehicles. When following the analysis results we can also come to a conclusion regarding a type of operation under which a vehicle was run. The dependencies found are shown in Fig. 1.

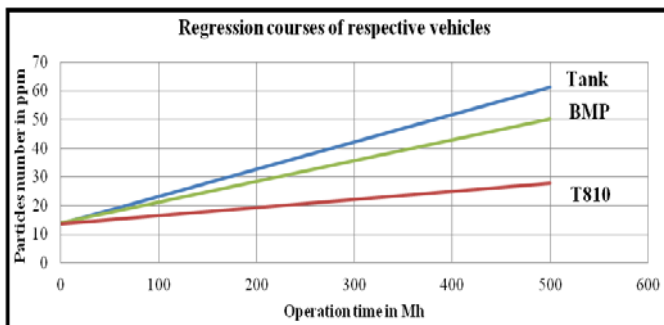


Fig. 1 Regression courses of respective vehicle .

Taking into account the presented results we can state that there is an objective connection between the amount of generated Fe particles and the number of operating hours. In the paper we do not address other interesting elements like cuprum or lead. The reason why we did not do it is that during performed analyses we could not

verify the mathematical dependence of particles generation per operating hour.

5. Conclusions

The aim of the paper is to shed light on the area of tribodiagnostics including the methods which are applicable and suitable for oil analysis.

The data regarding lubrication fluid which is available due to performed analyses is a good source of information when considering the cost savings provided the oil is changed systematically. It would be also good to see the results of the analysis in a broader context as an interesting reflection of an actual state of a technical object from where the oil was taken. When taking into account the results of the tribological analysis, the cost savings might be manifested as the extension of oil changes time and relating maintenance costs and downtime resulting from object unavailability by extraneous causes [3]. Since there is a wide spectrum of suitable methods while analysing an immediate state and prognosis (PHM – Prognostics and Health Monitoring), and because the area falls very deeply into interdisciplinary studies, the specification of relevant dependencies of the analysis results on a real technical state is not at all an easy task to do.

Having this tool we are capable of understanding the mechanisms of failures better. Such procedures enable us to be prepared for coming failures and progression to faults. The diagnostics is cheaper than on-line assets and failure mechanisms are determinable in advance. Some specific classifications of failures are also used in relation to risk sources and they are recognised due to oil and other life fluids diagnostics [7].

The results shown in Figure 1 for example demonstrate quite clearly that it is possible to assess the state of a system depending on oil data. It is obvious that a type of a motor data corresponds to the obtained results of the analysis and an assumed operating profile.

We believe that later in our research we will determine recommended optimum period for changing the oil. By the help of fuzzy logic [8] we expect to specify our information about operating history or the estimation of remaining operating units.

6. Literature

1. Gesellschaft für Tribologie e.V. GfT Arbeitsblatt 7: Tribologie - Verschleiß, Reibung, Definitionen, Begriffe, Prüfung (GfT, Moers), 2002. In German.
2. Czichos, H., Habig, K.H. Tribologie-Handbuch; Reibung und Verschleiß, 2nd edition. Weisbaden: Vieweg. In German, 2003.
3. Koucky, M., Valis, D. Suitable approach for non-traditional determination of system health and prognostics. *Zeszyty naukowe, Styczen – Marzec, Vol.1, No 159, p. 123-134. ISSN 1731 – 8157, 2011.*
4. Koucky, M., Valis, D. Deterioration Dependability Diagnostics. Revised by J. Čáp, V. Pištěk, F. Pešlová. Brno : handsdesign, Section II., Diagnostics – on approaches for non-destructive diagnostics, p.77-86. ISBN 978-80-254-8377-0. 2010.
5. Lippay J. Tribological diagnostics of heavy of road lorries Tatra 815 engines which operate with OA-M6 ADS II oil. Inauguration Thesis, Brno: Military Academy. In Czech, 1991.
6. Mamdani, E.H. Applications of fuzzy logic to approximate reasoning using linguistic synthesis, *IEEE Transactions on Computers, Vol. 26, No. 12, 1182-1191, 1977*
7. Valis, D., Bartlett, L. The Failure Phenomenon: A Critique. *International Journal of Performability Engineering, [online]. March, Vol.6, No 2. p. 181-190 [cit. 2010-03-16]. ISSN 0973 – 1318.*
8. Žák, L. Prediction of Fuzzy Times Series applying Fuzzy Inference System, *Mendel 2011, 17th International Conference on Soft Computing, 2010, Brno, 2011, pp. 148-153, ISSN 1803-3814.*

RESEARCH ON THE INFLUENCE OF THE TYPE OF MICROFILLER ON THE DAMPING CHARACTERISTICS OF POLYMER-CONCRETE COMPOSITES

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Abstract: This research presents the experimental approach and methodics for quantification of the damping characteristics of two groups of polymer-concrete composites. By means of a comparative analysis here it is determined the influence of the type of fine filler material (microfiller) on the damping characteristics of the experimental polymer-concrete composites.

Keywords: polymer-concrete composites, units, body elements, damping characteristics, modal analysis.

1. Introduction

Known in the beginning in the construction industry, today polymer-concrete composite (PCC) materials gradually, but certainly replace the conventional construction materials in the machine building practice. The good tensile and deformation characteristics and especially their very good damping behavior are prerequisites for the alternative application of the PCC in the production of units and body details for machine tools (MT) and for other production equipment.

2. Concise theoretical prerequisites

PCC are non-metal, viscous-elastic, quasi-isotropic materials characterized with high density of mineral disperse fillers. In terms of physicochemical mechanics they are solid macrodispersed systems (structures) that possess phase composition and interfacial boundary. Usually PC composites consist of two solid phases (matrix and filler) and one or two fluid phases (gaseous or liquid). For interfacial boundary between the solid phases serves the surface of the filler, while between the solid and fluid phases – the surface of the pores and gaps.

As matrix (binding substance) in the PCC is used the thermoreactive or thermoplastic synthetic polymer (resin) that is filled in with mineral microfiller (fine filler) with considerable surface. Thus the cavities' volume of the filler, instead with resin, is filled with matrix that demonstrates improved elastic characteristics and reduced deformability. The size of the particles and the quantity of the fine filler inhibit the micro fissures and enhance the adhesive bonds, which ensures the achievement of a very compact "packaging" of the polydisperse solid granules of the filler. Thus a solid hard 3D (3-dimensional) framework of the PC conglomerate is formed.

3. Expose

The subject of research of this work – gamma thermoreactive (based on unsaturated polyester resin) PCC, are developed and tested in the Laboratory of testing and research of machine tools at the Technical University Sofia, Plovdiv Branch. They possess enough resilience, demanded from the structural materials used for units and body details and very good damping characteristics. From chemico-technological aspect the developed new different experimental PCC are in fact multi-component systems (mixtures), which components are interdependent and bilaterally restricted. Fig. 1 shows the theoretic geometric model of the PC structure [1].

Subject of this research are the damping characteristics of the above-mentioned PCC and particularly the influence of the type of fine filler (microfiller) on these characteristics.

The fine filler (microfiller) is one of the components of the polymer-concrete composites. The size of its particles is less than 125µm. In the course of the experimental work the following materials are used as fine filler:

- A. Marble powder (classical version of the formulation);
- B. Quartz powder.

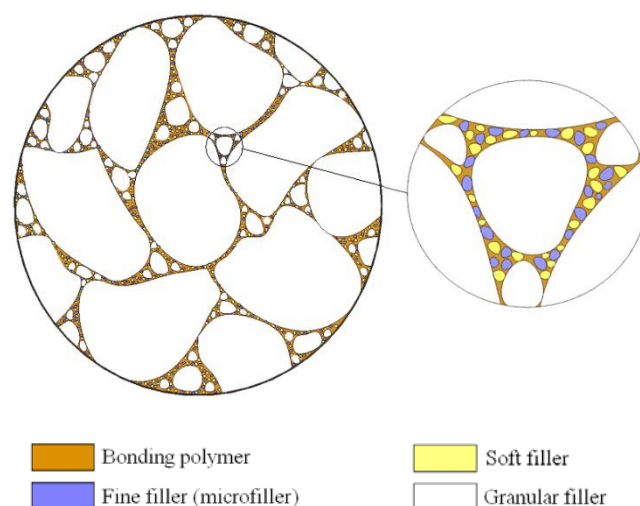


Fig.1. Theoretic geometric model of PC structure

3.1. Methodics of the research

In order to provide a solution for the task set in this research, here are presented the approach, ways and methods of conducting the experimental research. The influence of the type of fine filler on the damping characteristics of the PCC is determined according to the method of the similarity and comparison. For this purpose, two groups of polymer-concrete samples (test tubes) are used, respectively:

- First group: three polymer-concrete test tubes containing respectively ПБИП4, ПБИП8, ПБИП13, in which the microfiller is marble powder;
- Second group: three polymer-concrete test tubes containing respectively ПБИП4*, ПБИП8*, ПБИП13*, in which the microfiller is quartz powder.

The proportions of the respective PCC of both groups are the same. They differ only in the type of the microfiller in them. For the purpose of the comparative analysis it is accepted that the content of

the microfiller in the PCC of both groups to be the at maximum level, i.e. – 14%.

The sample units have rectangular parallelepiped form (a small bar) with dimensions 30×30×350 mm, Fig.2. In order to eliminate random errors, 3 sample test tubes of each composite are prepared.

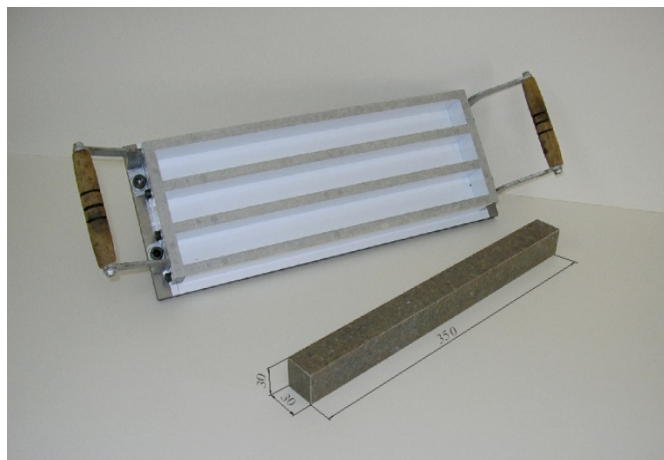


Fig.2. Sample unit and equipment for its making

The quantification of the damping characteristics of the PCC is difficult through direct measurement. Usually, in experimental conditions this happens on the basis of the parameters of the dynamic response of the tested samples, [2]. For the purpose of quantifying the damping characteristics the following experimental approach is applied: The tested sample unit is firmly fixed into a machine clamp, similarly to a bracket-fixed end of a bar. The machine clamp is fixed on a fundament or on a work table of a milling or other machine tool, with fixed vertical, transverse and longitudinal slides. Dynamic influence (excitation), in the form of forced mechanical vibrations, is applied on the free end of the bar. In this way the model of the multi-mass (with distributed parameters) vibrating dynamic system is implemented. The excitation of the forced vibrations in the dynamic system of the samples (test tubes) can be done by two methods:

- by means of variable sinusoidal (harmonic) excitation;
- by means of impulse (impact) excitation.

3.2. Experimental setting

The dynamic response of the tested unit, manifesting itself as transverse vibrations (in movement, speed or acceleration) is registered by vibration measurement and analysis equipment, by means of the accelerometer attached to the free end of the sample unit, Fig. 3 [1]. In the experimental setting shown on Fig. 3, the PC samples are excited through the impulse method, while the damping characteristics are determined through analysis of the damping forced oscillations.

The experimental determination of the damping characteristics of the PC samples is made according to the method of the modal analysis, [3]. The following damping characteristics are determined:

- damped (resonant) frequency - $f_d(\omega_d)$;
- 3dB bandwidth - $\Delta f(\Delta\omega)$;
- dimensionless damping ratio - ξ ;
- logarithmic decrement - δ ;

- modal decay rate - σ ;
- loss factor (absorption coefficient) - η ;
- quality factor (resonant quality) - Q ;
- 8,7dB decay time - τ_d .



Fig.3 Experimental setting

The functional relationships between the damping characteristics are shown with equation (1) and deduced in [1]:

$$\frac{\Delta\omega}{\omega_d} = 2\xi = \frac{1}{Q} = \eta = \frac{\delta}{\pi} = \frac{2\sigma}{\omega_d} = \frac{2}{\omega_d\tau_d}, \quad (1)$$

By analysis of (1) it can be seen that with increasing the values of the characteristics: $\Delta f(\Delta\omega)$, ξ , δ , σ and η the damping capacity of the PCC proportionally increases, and vise versa: with increasing the values of the characteristics $f_d(\omega_d)$ and Q reduces the damping capacity of the PCC.

The vibration measurement and analysis equipment (complete equipment set by Brüel & Kjaer) directly reports: natural damping frequency - $f_d(\omega_d)$, 3dB bandwidth - $\Delta f(\Delta\omega)$ and dimensionless damping ratio - ξ . The other damping characteristics are quantified according to (1).

3.3. Results of the experiment

On the basis of the so proposed methodics 2 groups of experimental results are obtained. The first group contains the results for the damping characteristics of PCC ПБИП4, ПБИП8, ПБИП13, in which the microfiller is marble powder, Table 1.

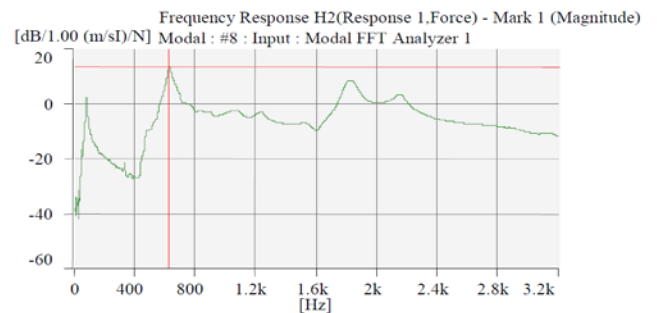
PCC with microfiller – Marble powder		Sample no.	Damping characteristics' values							
No	Polymer concrete make		Measured			Calculated				
			f_d	3dB Δf	ξ	δ	Q	η	σ	τ_d
4	ПБИП4	4.1	695.0	37.25	0.0268	0.1683	18.657	0.054	116.971	0.0085
		4.2	727.0	39.72	0.0273	0.1714	18.315	0.055	124.640	0.0080
		4.3	711.0	37.68	0.0265	0.1664	18.868	0.053	118.325	0.0085
8	ПБИП8	8.1	627.5	30.92	0.0248	0.1557	20.161	0.050	97.729	0.0102
		8.2	644.0	31.29	0.0243	0.1526	20.576	0.049	98.277	0.0102
		8.3	653.0	30.95	0.0237	0.1488	21.097	0.047	97.190	0.0103
13	ПБИП13	13.1	703.0	56.09	0.0399	0.2506	12.531	0.080	176.152	0.0057
		13.2	663.0	53.7	0.0405	0.2543	12.346	0.081	168.627	0.0059
		13.2	670.0	55.11	0.0411	0.2581	12.165	0.082	172.932	0.0058

Table 2

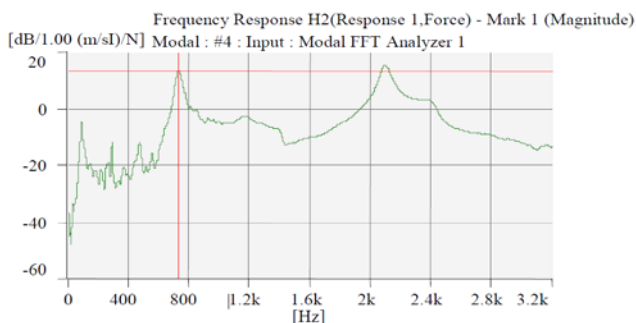
PCC with microfiller – quartz powder		Sample no.	Damping characteristics' values							
No Polymer concrete make			Measured			Calculated				
			f_d	3dB Δf	ξ	δ	Q	η	σ	τ_d
4*	ПБИП4*	4.1*	721.0	40.23	0.0279	0.1752	17.921	0.056	126.33	0.0079
		4.2*	732.0	41.68	0.0285	0.1790	17.544	0.057	131.01	0.0076
		4.3*	707.5	38.77	0.0274	0.1721	18.248	0.055	121.74	0.0082
8*	ПБИП8*	8.1*	668.0	34.06	0.0255	0.1601	19.608	0.051	106.97	0.0093
		8.2*	671.0	33.01	0.0246	0.1545	20.325	0.049	103.66	0.0096
		8.3*	655.0	35.09	0.0267	0.1677	18.727	0.053	109.83	0.0091
13*	ПБИП13*	13.1*	595.5	48.23	0.0405	0.2543	12.346	0.081	151.46	0.0066
		13.2*	683.5	57.37	0.0419	0.2631	11.933	0.084	179.85	0.0056
		13.3*	645.0	51.34	0.0398	0.2499	12.563	0.080	161.21	0.0062

The second group contains the results for the damping characteristics of the PCC ПБИП4*, ПБИП8*, ПБИП13*, in which the microfiller is quartz powder, Table 2.

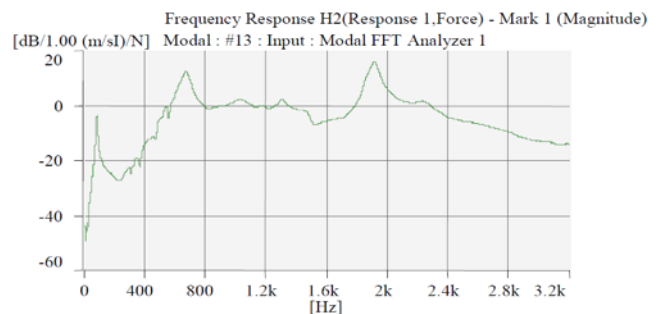
The obtained experimental results are based on reports that are automatically generated by the vibration measurement and analysis equipment, Fig. 4.



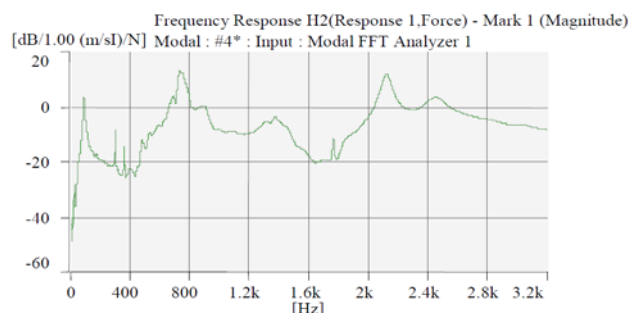
Resonance
Frequency = 627.5 Hz;
Delta f 3dB = 31.18 Hz;
Damping Ratio = 2.48 %



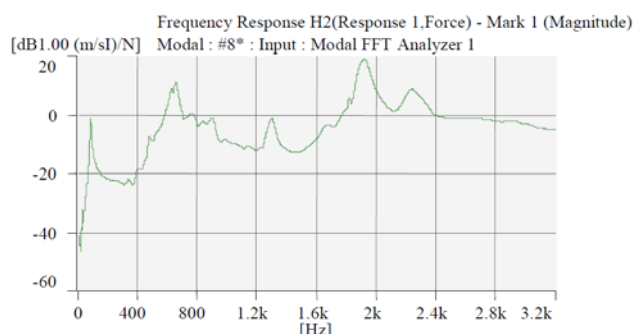
Resonance
Frequency = 727.0 Hz;
Delta f 3dB = 39.72 Hz;
Damping Ratio = 2.73 %



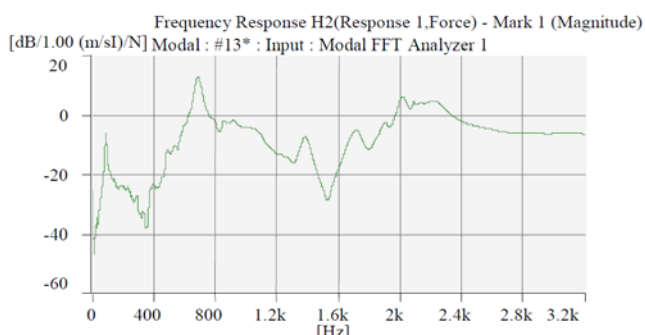
Resonance
Frequency = 670.0 Hz;
Delta f 3dB = 55.11 Hz;
Damping Ratio = 4.11 %



Resonance
 Frequency = 732.0 Hz;
 Delta f 3dB = 41.68 Hz;
 Damping Ratio = 2.85 %



Resonance
 Frequency = 655.0 Hz;
 Delta f 3dB = 35.1 Hz;
 Damping Ratio = 2.67 %



Resonance
 Frequency = 683.5 Hz;
 Delta f 3dB = 57.37 Hz;
 Damping Ratio = 4.19 %

Fig.4. Reports of amplitude frequencies for determining the damping characteristics

4. Conclusion

The choice of fillers and microfillers for the formation of polymer-concrete composites is dictated by the predetermined, desired characteristics of the material. By their type and quantity, the resilience, deformation, thermotechnical and damping characteristics of the polymer-concrete structure can be regulated. On the basis of the comparative analysis of the damping characteristics of the respective couples of experimental PCC from both groups, it can be seen that quartz powder used as microfiller in PCC improves damping ($3,8 \div 9,7\%$) in the three experimental mixtures, marked with (*). This predetermines our preference for “quartz powder” as one of the components - fine filler (micro-filler) in PCC, applicable as structural material for the production of units and body details for machine tools and other production equipment.

5. The results of this work can be summarized in the following way:

- Original methodics is developed for the quantification of the damping characteristics of two groups of experimental polymer-concrete composites. In the first group, marble powder is used as microfiller, while in the second – quartz powder.
- Laboratory equipment is constructed and experimental setting is proposed, both ensuring the experimental work.
- On the grounds of the viscous damping concept and the viscous-elastic deformation hypothesis of Feucht, here is presented a relationship for the functional relationships between the damping characteristics of the experimental polymer-concrete composites.
- This work proposes, also, and experimentally proves, an original method for quantification of the damping characteristics of the polymer-concrete composites, i.e. the method of the experimental modal analysis.
- On the grounds of the obtained experimental results from the reports and the performed comparative analysis, it has been found out that quartz powder as a microfiller in polymer-concrete composites ПБИП4*, ПБИП8* and ПБИП13* improves their damping characteristics with $3,8 \div 9,7\%$.

References

1. Popov, I. Research and optimization of polymer-concrete composites in reference to their damping characteristics. PhD thesis, Sofia, 2013.
2. Zlatanov, V., Buchvarov, S., Atanasova, S. Vibration of a Load Elastic Suspended for Elastic Beam through Another Load. Machine Design, Vol.4, 2012, No.1, p.33-42.
3. Avitabile, P. Experimental Modal Analysis. Sound and vibration, January 2001.

TRACKED VEHICLE ANALYSIS WITH SIMULATION TECHNOLOGIES SUPPORT

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Abstract: The paper is focused on the analysis of tracked vehicle propulsion mechanism during a movement of the vehicle. Propulsion mechanisms of tracked vehicles are highly loaded by dynamics stress. This stress arises by vehicle movement on a terrain and by vibration of tracks. Analysis of this stress is essential in the process of development or optimization (modernization) of the vehicle. Simulating technology was chosen for analysis of selected vehicle, because analysis of propulsion mechanism stress of tracked vehicle is complex process. Utilization of simulating technologies enables extensive analysis of vehicle behaviour including analysis of stress of main parts of the vehicle.

Keywords: TRACKED VEHICLE, SIMULATION, MOVEMENT, STRESS, DANAMICS

1. Introduction

Lethality, protection, mobility and communication are the general capabilities of the combat vehicle. Nowadays conflicts and military missions require different types of vehicles. Improving of the lethality and protection is current trend. Both these capabilities affect vehicle weight and its mobility.

Combat tracked vehicles are constructed for movement in a heavy terrain. Movement in this terrain increases requirements on chassis and whole propulsion mechanism. Especially transmission, sprocket wheels, idler mechanism and track elements are highly load by dynamic stress.

It is essential to analyze the stress of the main elements of transmission, its control mechanism and main parts of chassis for development of lifetime and reliability of propulsion system of the vehicle. This analysis is essential in process of vehicle optimization (usually weight increasing), too.

2. External load

We can divide external load of the propulsion mechanisms of the tracked vehicles into two groups – stress from track lines and stress from vehicle movement on the ground. The 1st group represents difference between wheeled and tracked vehicles. Utilization of the track lines arises additional forces. The 2nd group represents vehicle movement and its vibrations.

- stress from track lines:
 - by track tightening
 - by centrifugal force
 - by propelling force
- stress from vehicle movement on a terrain:
 - by vehicle vibration
 - track vibration

Track tightening F_t

Weight of the track lines affect magnitude of track tightening force. Track tightening is different for each vehicle. Track tightening influences possibility of track falling and magnitude of friction forces between track elements. Decreasing track tightening increases possibility of track falling and decreases friction forces. Optimal tightening of track line depends on character of a terrain.

Expressing magnitude of F_t by track line bend f is advantageous, because track tightening is characterized by track line bend on defined track part (Fig.1). Magnitude of f is possible to measure on standing vehicle.

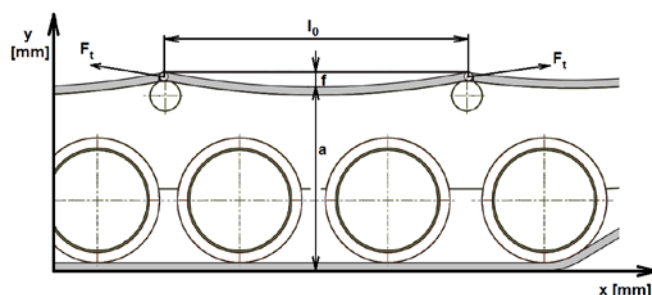


Fig. 1 Track tightening

We can mathematically express f by next equation²:

$$(1) f = \frac{1}{2} \cdot \frac{x^2}{a} = \frac{1}{8} \cdot \frac{l_0^2}{a}$$

where l_0 is distance between support rolls, x - distance in x axes, a - vertical distance between the bend track element and the ground.

Magnitude of track tightening can be expressed by next formula²:

$$(2) F_t = m_{te} \cdot a = \frac{m_{te} \cdot g \cdot l_0^2}{8 \cdot f}$$

where m_{te} is weight of the track element.

Centrifugal force F_c

Track line is during track rewinding loaded by centrifugal forces. These centrifugal forces arise additional load of the track line. Magnitude of this force can be expressed by next formula:

$$(3) F_c = m_{te} \cdot v^2$$

where m_{te} is weight of an track element, v - relative speed of the track.

Propelling force F_p

Part of the track is loaded by propelling force. Length of the loaded part depends on a position of the sprocket wheel. This stress affects load if idler mechanisms, too. Dependency of sprocket wheel position and length of loaded part is shown in the Fig. 2. Magnitude of this load can be expressed by following formula:

$$(4) F_p = \frac{T_{sw}}{r_{sw}}$$

where T_{sw} is sprocket wheel torque, r_{sw} - radius of a sprocket wheel.

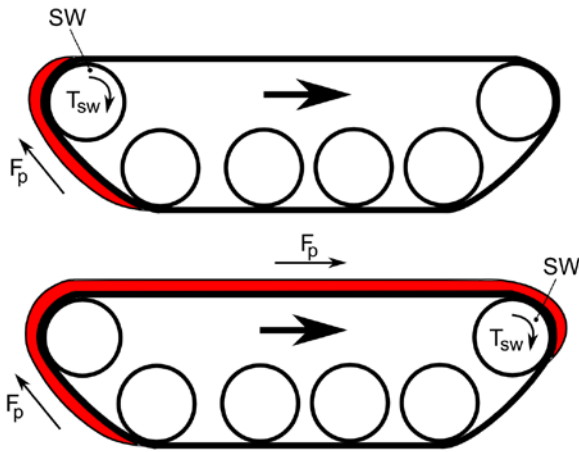


Fig. 2 Propelling force – up - sprocket wheel in the back, down - sprocket wheel in the front

Stress from vehicle vibrations F_v

Vehicle vibrations which are produced during vehicle movement over rough ground depends on vehicle speed, terrain geometry surface and dynamic characteristics of suspension system. A good insight into the effect of these characteristics can be gained by considering a simple, single degree of freedom model of a vehicle moving over a surface with a sinusoidal profile (Fig. 3)¹.

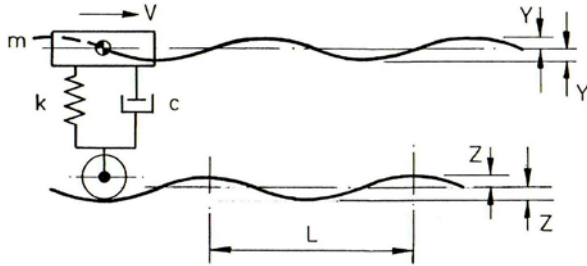


Fig. 3 Simple, single degree of freedom model of a vehicle moving over a sinusoidal surface¹

Vehicle is represented by a mass m connected by a linear spring of stiffness k and a damper with damping coefficient c to a wheel of negligible mass which follows the profile of the surface. If the vehicle is moving with a constant horizontal velocity v , the amplitude of its vertical oscillation Y is given by the following solution¹:

$$(5) \quad \frac{Y}{Z} = \frac{\sqrt{1 + 4\xi^2 \left(\frac{\omega}{\omega_n}\right)^2}}{\sqrt{\left[1 - \left(\frac{\omega}{\omega_n}\right)^2\right]^2 + 4\xi^2 \left(\frac{\omega}{\omega_n}\right)^2}}$$

where Z is amplitude of sinusoidal surface profile, ω_n - natural frequency of vehicle, ω - forcing frequency, ξ - damping ratio.

Vehicle vibration analysis is a complex process, especially for vehicle movement on the undefined terrain. Vehicle behaviour depends on the suspension system parameters and its interactions. Analysis of vibrations of the track lines is more complicated process because vibrations and movement of the vehicle have an influence on the track line vibrations. The next parameters mainly affect track lines vibration:

- vehicle vibration – defined by suspension system
- vehicle speed
- terrain surface
- kinematics of the track moving mechanism
- type of a track and connectors
- characteristics of road wheels

Basic bonds, parameters and degrees of freedom of the track line are shown in the next picture (Fig. 4).

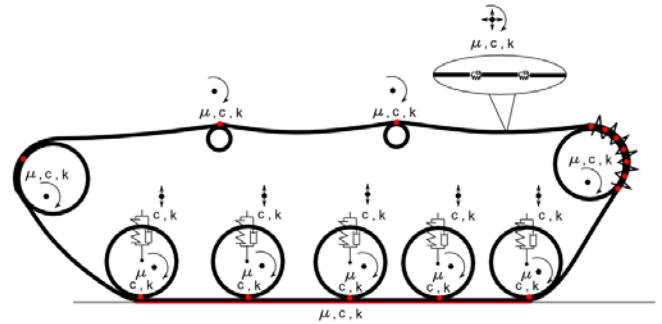


Fig. 4 Kinematic schema of a track moving mechanism

Vehicle movement and vibrations and track vibrations affect additional load force. This track force has highly dynamics character. Its magnitude depends on a lot of parameters and it is very difficult to mathematical express their dependency. From this point of view it is very efficient to use mathematic modeling and simulations for their analysis.

Simulating technologies are widely spread in all of spheres of industry. Possibility of complex analysis of stress of defined part of a system is first advantage of this methodology. We can record defined parameters (e.g. position, speed, stress) of defined element during whole process of simulation. Next benefit is that this manner enables not only assessment and evaluation of fixed vehicle configuration, but also enables assessment and evaluation of various vehicle modifications (e.g. chassis, main body, power units, protection systems, etc.) without necessity for real vehicle manufacturing. It is possible to compare different construction ideas in same operational environment and under the same conditions. Simulation of various critical states and behavior of vehicle (e.g. destruction of wheel, main body, etc.) is another benefit.

3. Utilization of simulating technology

I have used Multibody Dynamics (MBD) software ADAMS for creating of mathematic model of a tracked vehicle. This software enables to create complex model with full range of motion and operating environments. Optional modules available with Adams allow users to build and test virtual prototypes that accurately account for the interactions between main subsystems. Along with extensive analysis capabilities, Adams is optimized for large-scale problems, taking advantage of high performance computing environments³.

I have selected vehicle BMP-2 for application of simulation technology. The BMP-2 is amphibious infantry fighting vehicle introduced in the 1980s in the Soviet Union. Picture of this tracked vehicle is shown in the next picture (Fig. 5).



Fig. 5 Vehicle BMP-2⁴

Chassis of BMP-2 consists of 12 road wheels, 2 sprocket wheels, 2 idler mechanism, 6 support rolls (85 track segments) and suspension system (torsion bars + hydraulic dampers on the 1st, 2nd and 6th road wheels). Sprocket wheel is located in front part of the vehicle.

Basic parameters of the vehicle BMP-2 are⁵:

- length with gun forward 6735 mm
- max. width 3180 mm
- max. height 2450 mm
- combat weight 13900 kg
- max. engine power 221 kW
- max. engine torque 980 Nm
- track lines distance 2550 mm
- track width 300 mm
- length of track surface in touch with ground 3600 mm
- max. speed 65 km/h
- 5 gears forward, 1 gear backward

Mathematic model of BMP-2 was created according to basic parameters and kinematics of BMP-2 chassis. Created model is shown in the next picture (Fig. 6).

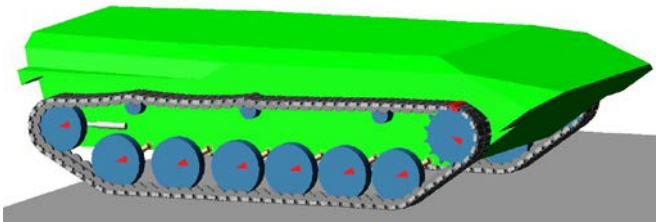


Fig. 6 Mathematic model of the vehicle BMP-2

One part of the model is ground. Physical parameters of the terrain meet the requirements of strengthened road → minimal deformations of the road → stress of the main parts of the chassis is maximal on this type of the ground.

For the basic analysis of the stress of main parts of track line were selected 4 types of the surfaces - straight road (Track A) and 3 types of a sinusoidal surface (according to theory) (Track B – D). Comparison of these sinusoidal surfaces is shown in the next picture (Fig. 7).

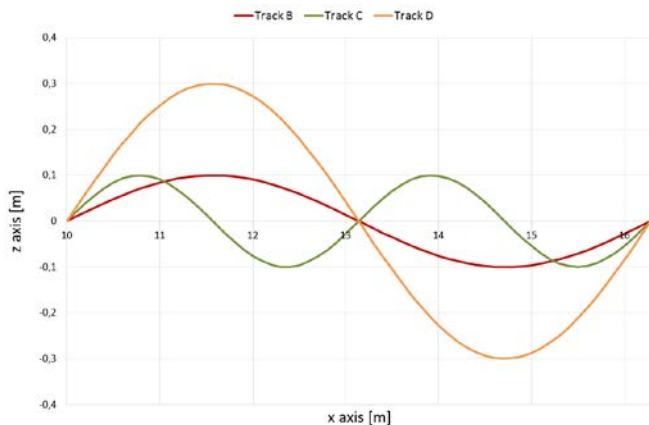


Fig. 7 Surfaces of track B - D

Propulsion mechanisms of the model is active → keeps defined vehicle speed by torque change. Maximal magnitude of the torque was counted for each gear (according to gear ratio – Table 1).

Table 1: Overall gear ratios⁵

no of gear	1 st	2 nd	3 rd	4 th	5 th
gear ratio [-]	28,875	15,631	10,516	7,062	4,719

Basic parameters of simulations were set:

- vehicle speed was 20 km/h a 40 km/h for each type of terrain
- vehicle overcame each type of terrain forward and backward – for analysis of influence of position of sprocket wheel into track and idler mechanism stress
- length of the simulations for 20 km/h was 6,5 s
- length of the simulations for 40 km/h was 3,2 s

4. Results

Stress of the idler mechanism and torque of sprocket wheel of the vehicle were selected as basic outcomes of proceeded simulations.

Magnitude of the idler mechanism stress can confirm theory of influence of position of sprocket wheel into overall track stress. There are shown courses of idler mechanism stress in the next graphs (Fig. 8 and 9). Track A – D forward movement, Track A r – D r backward movement.

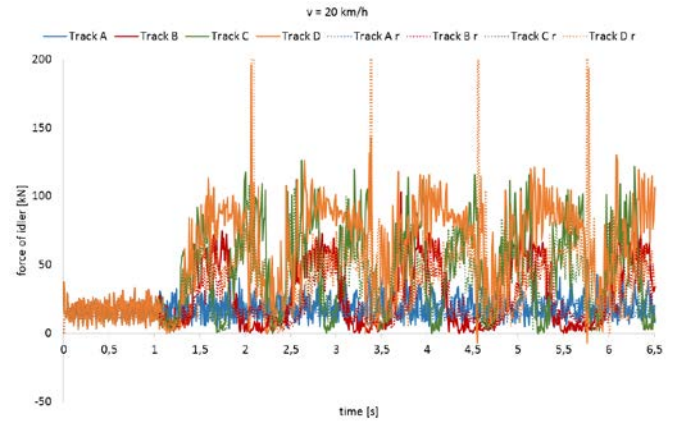


Fig. 8 Stress of idler mechanism, speed 20 km/h

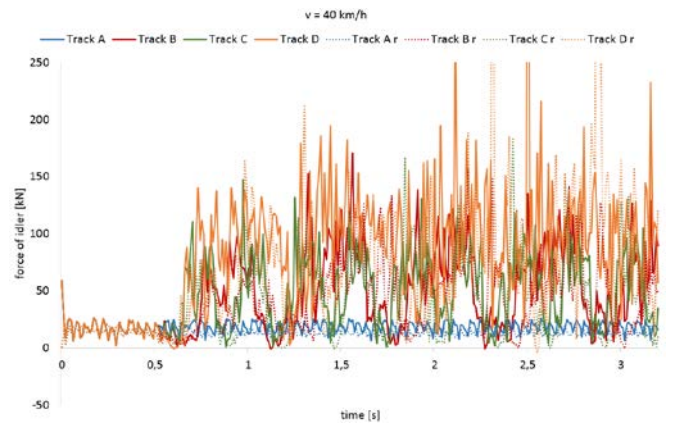


Fig. 9 Stress of idler mechanism, speed 40 km/h

From the courses of the force of idler mechanism we can find dependency of force course on the terrain surface. We can find that force of the idler mechanism has highly dynamics character, too. For better comparison of the force courses I have done linear extrapolation of these forces (Fig. 10 and 11).

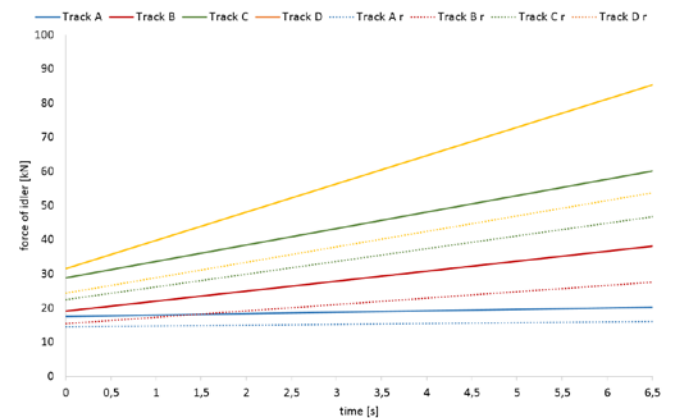


Fig. 10 Linear extrapolation of the idler mechanism stress, speed 20 km/h

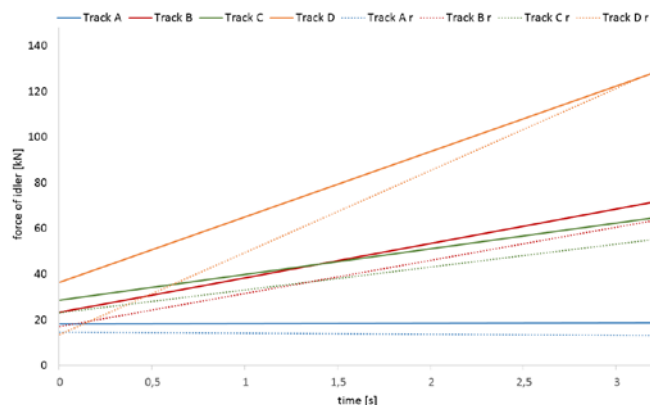


Fig. 11 Linear extrapolation of the idler mechanism stress, speed 40 km/h

From the graphs (Fig. 10 and 11) it is clear that stress of the idler mechanism with sprocket wheel in front of the vehicle is higher. Proceeded simulations has confirmed the theory.

Torque of the sprocket wheel (transmission) is the next outcome of the simulations (Fig. 12 and 13).

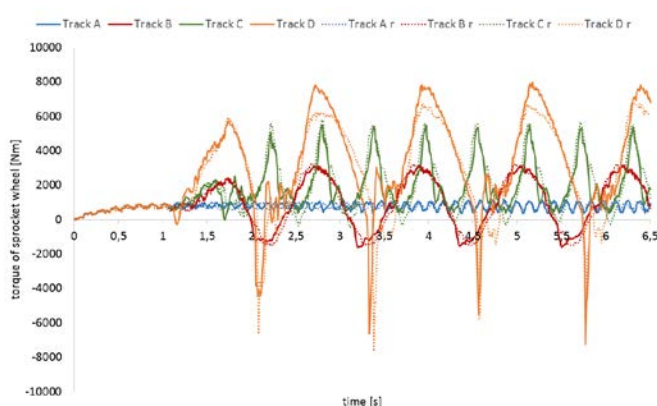


Fig. 12 Torque of the sprocket wheel, speed 20 km/h

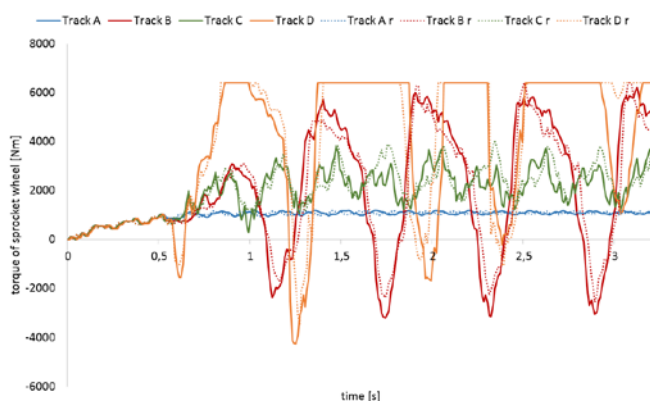


Fig. 13 Torque of the sprocket wheel, speed 40 km/h

Simulations confirmed that terrain surface affects stress of the sprocket wheel (track vibrations). We can find changes of the stress magnitude according to the sinusoidal course of the terrain in the graphs (Fig. 12 and 13).

We can find that magnitude of the engine torque on the tracks D and D r got to maximal value. Vehicle speed 40 km/h was too high for overcoming track D and D r and the vehicle was “jumping” on these types of the terrain (Fig. 14).

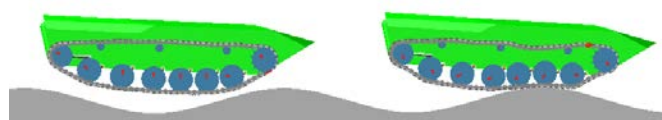


Fig. 14 Vehicle “jumping”, track D, speed 40 km/h

5. Conclusion

Sprocket wheel of tracked vehicles is loaded by forces arising by track tightening, by centrifugal force, by propelling force and by vibration of track lines. Position of sprocket wheel affects stress from propelling force. Track line vibrations affect vehicle vibrations, vehicle speed, terrain surface, parameters of the chassis, type of a track and connectors and parameters of road wheels. All these stresses highly dynamically load transmission mechanism.

The vehicle consists of a lot of movable parts, attachments and contacts defined by stiffness, damping and friction coefficients. It means that vehicle is complicated mechanism and the analysis of the stress of the main parts of the chassis is a complex process. Simulation technologies are very efficient manner for analysis of this complex system.

I have used Multibody Dynamics software ADAMS of MSC Software for application of simulating technologies. The vehicle BMP-2 was selected for this type of analysis. Mathematic model of BMP-2 was created according to basic parameters and kinematics of BMP-2 chassis.

Model analysis was performed during the model movement on the 4 types of terrain – A – flat; B, C and D – sinusoidal. Sinusoidal courses of terrain were selected for verification of theory of vehicle vibrations influence. Vehicle was moving by speed 20 and 40 km/h, forward and backward.

Proceeded simulations has confirmed the theory that stress of the idler mechanism with sprocket wheel in front of the vehicle is higher than with sprocket wheel in the back of the vehicle. Top branch of the track is loaded by this additional force, too. And this force has highly dynamic character.

Simulations confirmed that changes of the torque of the sprocket wheel depend on the course of the terrain. We can find sinusoidal course of this stress, too. Torque of the sprocket wheel has highly dynamic character.

Speed 40 km/h was inappropriate for terrains D and D r, because the vehicle was “jumping” on these types of the terrain. Engine torque got to maximal value on this terrain by speed 40 km/h.

Simulating technologies are appropriate for vehicle movement analysis and for analysis of the stress of the main parts of the chassis and transmission mechanism.

Acknowledgement

Presented work has been prepared with the support of the Ministry of Defence of the Czech Republic, Partial Project for Institutional Development, K-202, Department of Combat and Special Vehicles, University of Defence, Brno.

References

- [1] Ogorkiewicz, Richard M. Technology of tanks. Coulsdon, Surrey: Jane's Information Group, 1991, 2 v. (424 p.). ISBN 07-106-0595-1.
- [2] Kolybelík, I. Combat tracked vehicles: Mechanics of movement. Brno: Military academy, 1985, 412 s. (Bojová pásová vozidla: Mechanika pohybu)
- [3] MCS.software. [online]. [cit. 2014-04-02]. Available from: <http://www.mscsoftware.com/product/adams>.
- [4] Wikipedia. [online]. [cit. 2014-04-02]. Available from: <http://upload.wikimedia.org/wikipedia/commons/6/60/BMP-2.JPG>.
- [5] Combat infantry vehicle 2 (BMP-2): Description. Praha, 2000, 356 s. (Bojové vozidlo pěchoty 2 (BVP-2): Popis)

NEW TRENDS IN TRAFFIC SAFETY

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Abstract: In this paper the important events in the auto industry all over the world, situation with automobile industry in Serbia, the concern for safety of drivers and other participants in traffic, with special stress on the protection of children in traffic, as well as the obligation of environmental protection are presented. Unfortunately, mortality in traffic is becoming epidemic. The interactive map showing the basic parameters of traffic safety in all countries in the world has been started. Every year on the roads throughout the world even 1.240.000 persons are killed. On the roads in Serbia the most frequent causes of traffic accident with serious consequences are: speeding, driving under the influence of alcohol and not fastening seat belts. Children in traffic are killed mostly as passengers. Research shows that Serbia is positioned very low comparing to European Union countries when it comes to the safe transport of children in vehicles and the use of seat belts. Agency for Traffic Safety in the Republic of Serbia in December 2013 celebrated 4 years from foundation and on that occasion the importance and necessity of connecting and coordination in work of all subjects competent for the field of safety was emphasized.

Key words: AUTO INDUSTRY, TRAFFIC SAFETY, ENVIRONMENT, PROTECTION, SERBIA.

1. Introduction

In March 2012, on the International Car Show in Genève, Serbo-Italian automobile "Fiat 500L" had its world's premiere and then it was stated precisely that this automobile is going to be produced only in Kragujevac, in Serbia.

The important changes are happening all over the world. During October 2013 public was informed about the action of the women from Saudi Arabia, who took the steering wheels in their hands in spite of the prohibition of the Government. Defying to the measures of the Government, threats of arrest and criminal prosecution, few women were driving cars in the streets of the Saudian towns. Then The King Abdulach gave support to some cautious reformes, such as the development of women's education and their employment, taking care to avoid the conflict with conservatives.

In this paper important events in the auto industry all over the world, situation with automobile industry in Serbia, obligation of the environmental protection, as well as the concern for safety of drivers and other participants in traffic, with special stress on the protection of children in traffic are presented.

Organization of Serbian drivers pointed out to their rights that they are also fighting for: - the obligatory privileged length of service, - recognizing of daily wages in foreign currency for drivers for the days spent abroad, - and to respect the rights of drivers and the help "friend on the road"

2. News in the world and in Serbia in the area of Auto Industry

Italian "Fiat"¹ has very strong presence on the American market. In 2013 in Detroit negotiations with trade union of automobile workers were successfully ended and conditions for Italian producer "Fiat"² to become 100% owner of the "Crysler" and car company with global reach were created. This agreement was realized and in 2014. "Fiat" completely took over "Crysler", the smallest member of the Detroit "big three", founded in 1925.

At the same time Serbian Auto-Moto Union reported that according to all criteria of the Euro NCAP tests for security the Chinese car "Coros 3 Sedan" was the best in 2013³. This car achieved the best result with maximal five stars in all segments of evaluation.

At the Serbian market models "Nissan Qashqai 360 Family" as well as "Nissan Juke", alluring from the advertisements in our surroundings at the end of 2013, are offered.

Cooperation with "Mercedes" company is dated from 1997.⁴ when the long-term contract on cooperation in production and investment in the "Mercedes-Benz Icarbus" buses was signed. And the contract on strategic cooperation between the world's giant in auto industry "Mercedes" and domestic producer of buses "Icarbus" should be signed in the middle of 2014. and then in Zemun⁵, near Belgrade the production of entire production program of Mercedes buses would start.

The first bus "Icarbus" was produced in 1954 by the license of the company "Saurer" from Austria. The founder of the "Icarbus" company was Dimitrije Konjović, a Serbian pilot and a maritime officer. In 1968 year the first bus with its own frame was produced and till today more than 80% of produced buses are with "Icarbus" frames. The production of the prototype bus on "Mercedes" frame has already started. This vehicle was made by the most modern standards and it was presented at the end of March 2014. on the International Fair of economic vehicles in Belgrade, Serbia. These are so called **gama models of buses** which meet strict professional but also ecological standards, because they have the motors of „euro 6“ standard. The present production capacity of "Icarbus" is around 250 buses per year.

In the world, "Detroit Auto Show", was held in USA where the "Lincoln" motor company presented the most fuel-efficient, inspired, innovative, ingenious new "Lincoln 2014 MKZ Hybrid". But since its start, in 1911. "Chevrolet" has sold more cars than any other auto maker providing itself to be the "US brand" in these iconic models. In 2013 "Ford" fuel-efficient line⁶ are as we know: "Fiesta", "Focus", "Fusion", "C-max", "Escape", "F-150" while they also must introduce all new 2015 "Ford Mustang" too.

It is interesting that competing with more than 1000 participants from the whole world Marko Luković⁷ from Belgrade, Serbia, for the second time won prize on the contest in Detroit, that is, the automobile of the Serbian designer is among the best in the

¹ The greatest Italian employer in private sector was founded in year 1899.

² In 2009. "Fiat" bought 58,5% of "Crysler", the smallest member of the Detroit "big three" at that time in bankruptcy. The sale of "Fiat" and "Fijata 500" produced in Mexico and "Fiat 500 L" coming from Serbia (on the market from the summer 2013.) during year 2013. was 1,4% less.

³ In 2012. year 33 vehicles were tested, and criteria were protection of adult passengers, children, pedestrians and safety equipment these vehicles have.

⁴ It was predicted that "Mercedes-Benz" delivers frames with aggregates and other equipment, and in "Icarbus" the buses of European standard and quality with recognizable sign of "Mercedes" are installed. By the contract production of 5 types of buses, among which "Icarbus" took over 2-low ground bus for city transportation and high-tourist class bus, encircling with this the assortment of its products, was defined. After realisation of few buses according to this contract, further cooperation was abandoned because of too high price for domestic market.

⁵ In Zemun section the most modern city, intercity and tourist buses, as well as pickup trucks will be made on "Mercedes" frames, while "Icarbus" would do the annex.

⁶ 2013 C-max Hybrid with fuel efficiency and smart technology too.

⁷ In 2001, this professor at the Faculty of applied arts in Belgrade, won the first "Peugeot" contest at the Frankfurt Car Salon with the futuristic car concept for year 2020.

world At "Detroit Auto Show" cool colors and concepts of cars were exhibited.

The "Tokyo Motor Show 2013" took place in Japan and the new "Toyota" named "Tundra" is at disposal in 2013. and "Toyotathon" and all new Nissan Rogue R.

In September 2013, the public was informed about all innovations in auto industry at the Car Salon in Frankfurt /Germany/. "Forester", the new "Subaru" model was presented.

The technological company "Google"⁸ appeared in the world of automobilism i.e. auto-moto industry came to an agreement with big producers (partnership was concluded with companies "Audi", "General Motors", "Honda" and "Hundai") at the opening of Auto Show in Las Vegas. Partners will think out together how to include mobile operative system "android" in cars operation, what should make operation more simple and improve safety. In that way, "Google" tends to reach the competitor "Apple" which has already been working on this with "Mercedes" company.

3. Importance of Environmental Protection

In the middle of May 2013, the draft Program for environmental protection of the city of Belgrade for the period of 10 years was presented with the aim to define directions of development and environmental management politics on the whole territory of the city and after the adoption it will be an obligatory document in the process of local policy creation in all 17 municipalities of Belgrade. This project predicts realization of several projects, the adequate treatment of waste waters and waste disposal being some of them. The city transportation company points out that the total consumption of fuel is about 100.000 liters on work days .

In our country, Pančevo will become the only local autonomy in Serbia with 7 vehicles with electric drive, and simultaneously the first charging spot⁹ for electrical cars.

The vehicle of the Chinese company "BID" that will be included in public transportation is currently being tested in our capital Belgrade. We speak about the new generation of high technology ecological buses, the use of which considerable reduces maintenance costs and improves air quality, because there is no emission of harmful gases.

It is well known that Germany is the residence of big car producers ("BMW", "Wolkswagen", "Deimler") and that the drafts of new EU regulations might endanger industrial production and its business sector.

Anyway, "Mercedes" has the famous bus brand "Setra" under its wing which currently produces the most modern and "the greenest" buses that do not in the least pollute the environment. In October 2013, the public found out that Germany protected its car industry from European Union (EU) regulations.

The Ministers of environmental protection of member countries of the European Union adopted the German request to alter already reached agreement on the introduction of the new regulation on the emission of harmful gasses of the new automobiles in June again. This agreement which is now going to be altered, would limit emission of CO₂ from new cars to 95 gr per covered kilometer by 2020. The implementation of the decision was prolonged by 4 years and activists for environmental protection have criticized that decision and the European Commissioner for climate changes, as well as director competent for EU transportation policy at "Greenpeace".

According to the European directives, by the end of 2020 we should increase the share of biofuels in public transportation fuel consumption. It is well known that the advantages of hybrid vehicles are at lower level of harmful gasses emission, smaller consumption of diesel fuel and lower noise level, while the shortcomings are certainly their high price, they are considerably

heavier than classic buses, the battery duration is limited and they require special maintenance and additional caution measures because they operate under high voltage of around 600 Volts (hybrid buses are used most in North America, where passengers are transported by around 6.200 buses, while they appeared in Europe not until 2007. and for the first time in London).

4. Traffic Safety - risks and solutions

Unfortunately, mortality in traffic is becoming epidemic. The interactive map showing the basic parameters of traffic safety in all countries in the world has been started. Every year on the roads throughout the world even 1.240.000 persons are killed. On the roads in Serbia the most frequent causes of traffic accident with serious consequences are: speeding, driving under the influence of alcohol and not fastening seat belts.¹⁰ Children in traffic are killed mostly as passengers. Research¹¹ shows that Serbia is positioned very low comparing to European Union countries when it comes to the safe transport of children in vehicles and the use of seat belts.

It is interesting that in Serbia during the last 4 years, around 300 drivers have passed "corrective" tests because their driving licence has been taken away for received 18 negative points. In the same period, close to 3000 drivers lost their licences because of violent driving.

Agency for Traffic Safety in the Republic of Serbia in December 2013 celebrated 4 years from foundation and on that occasion the importance and necessity of connecting and coordination in work of all subjects competent for the field of safety was emphasized.

However, thanks to the Law on traffic safety which came into force in December 2009, this year 176 persons less were killed in traffic accidents compared to the same period 4 years earlier.

During 2013 according to the newest data that number was reduced by more than 9%, i.e. 59 persons less were killed compared to the same period in 2012. We should point out that 2.813 pedestrians were killed in Serbia in the period from 2001 to 2012, and more than 13.000 were seriously and more than 28.000 slightly injured. Only last year 165 pedestrians were killed, that is by 10 more than in 2012. The results of this research are also the base for further activities of the Agency for Traffic Safety on the protection of pedestrians.

The UN action for traffic safety on the Planet is under way. United Nations have started global initiative titled "My world after 2015" in which they call for citizens of the Planet to choose the priorities for the better world and life in it (16 priority goals of human community development were offered, among which voters should choose the 6 most important).

The International Automobile Federation /FIA/ and Serbian Auto-Moto Union joined the action of the United Nations, because one of its parts is related to the improvement of road traffic safety. That is connected with the preparation of the Resolution on Global Road Traffic Safety in the framework of the 10 year-lasting action of the United Nations for traffic safety on the Planet from year 2011. to year 2020.

The idea to drive auto-plane that would be a combination of aircraft without pilot and car-robot coming from Technological Institute in Masachusets is interesting, but this is not favorite in public, because it is understood as the carrier of spy equipment. Those special machines would be computer-operated. Technology of wireless guidance is used by all "Airbus" and many "Boing" planes. Experts of aeronautics and astronautics consider that there

¹⁰ Examples of France and Germany show that in these countries 95% of passengers fasten seat belts also on the back seats in the vehicle, while in Serbia that percentage is barely 4% of passengers.

¹¹ Project with title "Methods of monitoring indicators of road safety and their importance for the strategic management of traffic safety" done by the Faculty of transport and traffic engineering in Belgrade on the request of the Agency for Traffic Safety, which is a member of the European Council for Road Safety.

⁸ The American internet giant „Google“ intends to expand its popular operative system „android“ in the cars.

⁹ This is the present of the Italian province Ravenna in order to protect environment.

are no obstacles for starting road-air traffic by flying cars – **DRONES**. However, there are certainly some cultural and psychological obstacles, because we are not ready to give up cars (published by “Tanjug” from London, at the beginning of November 2013.).

It is planned that **drones** will soon start to be part of the everyday life, for example, for delivering packages¹², but also as the assistance in space orientation. The laboratory of the American University MIT constructed a robot with the aim to help people, but it takes time to find the interaction between people and robots.

5. Conclusion

This paper is written with a wish that the cited newest improved models of automobiles throughout the world lead to as little as possible traffic accidents, injuries and destruction, to increase traffic safety in all countries, and also to reduce pollution that traffic causes. It should be insisted on the reduction of CO₂ emission by year 2025 and of course on its inclusion in the regulations. It is interesting that the position of Germany was supported by Great Britain and Poland, while France, Belgium and Italy took the original agreement's part.

It is necessary to stress in media and inform wider public on the importance of environmental aspects of traffic taking into consideration the well known fact how much cars reduce air quality by emission of harmful gases.

At the opening of Auto Show in Las Vegas company “Google”¹³ appeared in the world of auto-moto industry coming to an agreement with few big producers (partnership was concluded with companies “Audi”, “General Motors”, “Honda” and “Hundai”). Partners will think out together how to include mobile operative system “android” in cars operation, what should make that operation more simple and improve safety. It is well known that the price of the secret program of drones is high and that in the world debate “for drons and against them” is lasting. In the era of sophisticated technologies however humans are irreplaceable.

In the Republic of Serbia a lot is invested in the traffic safety on the national as well as on the local levels all over the country. Cooperation between countries is something we should lean on more in the future in order to find solutions for environmental and traffic safety problems easier and fight them together.

6. References

1. Djindjić N. et al. Work stress related lipid disorders and arterial hypertension in professional drivers – A cross-sectional study, *Military Medical and Pharmaceutical Journal of Serbia*, 2013, 70(6), 561-568.
2. Law on Road Traffic Safety, „Official Gazette RS“, no. 41/09, 53/10, 101/11.
3. Kombeg info, Privredna komora Beograda, no. 47, June 2013.46.

¹² Company „Amazon“ will use these aircrafts for delivering packages up to weight of 5 kilograms.

¹³ American internet giant „Google“ intends to expand its popular operative system „android“ in the cars.

TEST PLATFORM, DATA COLLECTION, SYSTEM IDENTIFICATION OF MULTICOPTER VEHICLE

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Abstract: Multicopters are widely used in a professional manner today in film industry, military applications etc. These vehicles are easy to build which have mechanical and electrical parts. Also autopilots are being sold to control these vehicles. However, mostly these vehicles are being built and used with little knowledge about the system dynamics, performance and stability. Mostly wrong propeller motor battery combinations are used. And mostly these vehicles are being used by different payloads. Every change in payload changes dynamics and stability of the vehicle. Very little of users are eligible at PID tuning and increasing the stability of multirotor vehicles. We aim to provide a test platform and methodology for system identification and increasing stability of Multirotor Vehicles.

KEYWORDS: MULTIROTOR, SYSTEM IDENTIFICATION, KALMAN FILTER, TEST PLATFORM, MATHEMATICAL MODEL

1. Introduction

In this study real time data collection and system identification of dynamic parameters of a multicopter type robotic vehicle is aimed. A test bed for safe testing of the vehicle and isolation of required degrees of freedom is built. Sensors are mounted and data is transferred to computer real time. The PC is used for development of sensor fusion algorithms, real time parameter estimation and adaptive control algorithm development and visualisation. On computer MATLAB Real Time Windows Target is used. The ultimate aim is to precisely model the multicopter vehicle, and build a robust controller. Sub Parts will be modeled as well as the whole vehicle. Stability analysis of single DOFs and cross coupling will be investigated. Kalman Filter for sensor fusion will be applied[1,5].

2. Design Considerations

Frame: there are many frame types available for multicopter design. The most important parameter of frame is its rigidity which should not let unwanted vibrations to be transferred from motor-props to the sensors. **Tricopter:** this frame type is formed by three arms and three prop-motors and a servo motor to control the tail motor roll angle. Since it is not symmetrical torque balance is obtained by tail servo. They suffer from less than stellar performance and are not suitable for larger sizes. **Quadcopter:** this frame is most common, it is symmetrical and embody the simplest principle of operation for controlling roll, pitch and yaw operation. There are many variations of Quadcopter frames, +, X, Dead Cat, H The X frame is considered best for flight performance and stability since its natural symmetry balances flying forces better. Long endurance multicopters are generally chosen X frame with low RPM high wattage and big size props. It is possible to obtain 60min flight times. Hexacopter and Octocopter are chosen for professional heavy lift tasks such as professional heavy lift cameras. In filming camera vibration is very important and should be omitted. With heavy lifts hexa and octo frames provide more stable less vibration flights. But at a cost of efficiency compared to quadcopters. Also they are more prone to failure since they have more components. It is a possibility with these frames to safely land even with one motor failure. Y6 and X8 frames are double contra rotating prop designs which provide most lift in smaller area, but again at a cost of efficiency. Which is about 20-30%

compared to regular frames. On the contrary, on heavy duty airplanes contra-rotating props have 7% more efficiency. The reason of different results is to be investigated. Maybe it is due to turbulence of downwash of upper propeller in multicopters since they turn slower compared to on airplanes. Its advantage is practical frequent usage due to its smaller size.

Power train(Motor-Prop-Battery): The flight time, take-off weight capacity, dynamic behaviour is mostly related to power train. The multicopter design should fit to the task. For long endurance multicopter lesser arm frame with low RPM high power motors matched with big size propellers and suitable voltage-weight battery should be chosen. Also the propeller pitch angle is chosen smaller. The higher the motor RPM needs to be the lesser is the efficiency. The long endurance designs are less stable with heavier payloads due to big prop sizes. For heavy duty applications a little bit higher RPM high power-to-weight motors are chosen. Not too high as airplane, since they use smaller high pitch propellers with high RPM motors. Frame is generally chosen Hexa or Octo for stability and chance of survival on one motor failure. If power to weight ratio high enough, autopilot will be able to safely control the multicopter, and save the expensive heavy payload.

Balance: The multicopter is an aerial platform and symmetry and balance is very important for stability of AC and long life of components and AC itself. The components should be so well located that the c.o.g of AC should be close to the geometrical center point of AC where Autopilot Inertial sensors are located. The motor and props should be well balanced, if props are not well balanced vibrations will occur and wear out the motors and props, which eventually will cause prop breakout or motor breakout. Also unbalanced motor or prop will cause vibrations on the Inertial sensors. The more vibrations on the IMU the more integration error becomes. Which will cause positioning errors at the absence of GPS. Vibration dampeners should be installed under the IMU sensors. The balancing of prop-motors is still necessary to prevent prop-motor breakouts[2].



Picture 1: X type frame quadcopter picture

3. Tests and Data Collection

Test apparatus data collection and system identification has been designed. One test bed is single axis Degree of Freedom ball bearing table for one axis, two axis and three axis dynamic behaviour investigation of multicopter. In this test bed yaw, torque, pilot stick input to roll, and pilot stick input to pitch response can be investigated and safely recorded for system identification.

Second test bed is power-train test bed where the whole components of the power train (Propeller-Motor-Motor Driver-Battery-Pilot input) can be tested at once. This test bed is good for finding the most efficient propeller-motor-battery combination, testing the motor driver performance, and collecting data for power-train transfer function system identification mathematical model.



Picture 2: Power train test platform

Power train system is tested using a variable power supply, precision scale, motor, propeller and motor driver with variable PWM input. Lift, Voltage, PWM Percentage, RPM, Current Drawn is measured. Also the effect of imbalance of propellers and motors due to RPM can be measured by adding an accelerometer to the test bench. Power train vibration reduction is problem which should be absolutely minimized. In table 1 the power train system measurements can be seen, most the measurements are omitted because of scarce space. 5 different motor, 10 different propellers, two voltage values are simultaneously measured.



Picture 3: 3DOF Test platform for quadcopter, multicopter and helicopter around ball bearing fixture

4. Sensors and Modelling

Magnetic Sensor Model: The MEMs sensor HMC5883 is used for measurement of Magnetic Heading

IMU Model: The MEMs IMU is MPU6050, in Simulink IMU model natural frequency, noise, bias, and damping parameters can be simulated.

Power-Train Model: Power train model is considered as combination of Battery-Motor Driver-Motor-Propeller. The input is a Pulse Width Modulation (PWM) signal from autopilot which is 1-2ms interval 50Hz signal (some autopilots may have shorter control loops.)

Earth magnetic model: The earth magnetic deviations are modelled using simulink. The mathematical model accepts date and GPS coordinates and gives the magnetic heading deviation. Earth magnetic model is constructed using USGS measurement database[3].

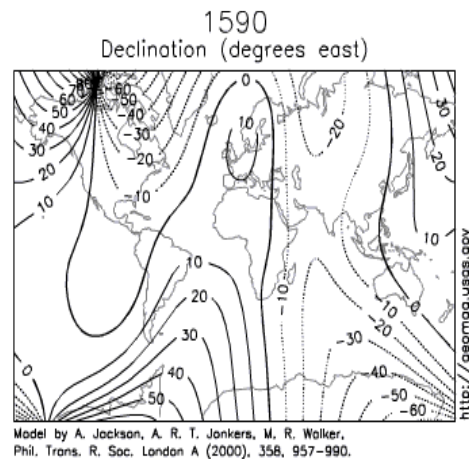


Figure 1 : Earth Magnetic Deviation Model.

Earth magnetic model shows us that the magnetic deviation is ± 20 degrees.

GPS model error is ± 10 m. GPS error is simulated using Zero-Order Gauss Noise.

The generalized coordinates for a rotorcraft are:

$$Q = (x, y, z, \theta, \phi, \psi)$$

Where (x, y, z) denote the position of the center of mass of the rotorcraft relative to the frame, and (θ, ϕ, ψ) are the three Euler angles which represent the orientation of the craft.

After calculations following are the non-linear equations of motion[1]:

$$m\ddot{x} = -u \sin \theta$$

$$m\ddot{y} = u \cos \theta \sin \varphi$$

$$m\ddot{z} = u \cos \theta \cos \varphi - mg$$

$$\ddot{\varphi} = \ddot{\tau}_{\varphi}$$

$$\ddot{\theta} = \ddot{\tau}_{\theta}$$

$$\ddot{\psi} = \ddot{\tau}_{\psi}$$

The first control input is u which is defined as follows:

$$u = f_1 + f_2 + f_3 + f_4$$

$$f_i = k \omega^2$$

The desired outputs for each individual motor can be calculated from the following equation:

$$\begin{bmatrix} u \\ \ddot{\tau}_{\theta} \\ \ddot{\tau}_{\varphi} \\ \ddot{\tau}_{\psi} \end{bmatrix} = \begin{bmatrix} 1 & 1 & 1 & 1 \\ -c & c & -c & c \\ 0 & -l & 0 & l \\ -l & 0 & l & 0 \end{bmatrix} \begin{bmatrix} F_1 \\ F_2 \\ F_3 \\ F_4 \end{bmatrix}$$

where c is the torque produced by each motor about the ψ axis and l is the moment arm to each motor[4].

5. System Identification

System identification is the process of measuring the inputs and outputs of a dynamical system and obtaining the mathematical model of system. For this purpose precise measurement and correct test system setup is very important. The control inputs scenarios should be carefully selected so as much as bandwidth of the system is considered. Inputs can

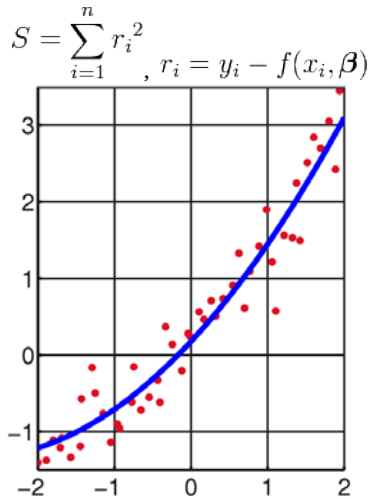


Figure 2 : Curve fitting with quadratic function

6. Precautions and means for resolving the problem

Testing the device on air is a time consuming and costly procedure. For overcoming this problem a 3DOF test platform is built. Any axis can be limited to individually test the vehicle while collecting data real time.

7. Simulation

Sensors are modelled and simulated using MATLAB Simulink software. In simulation Earth magnetic model, IMU, GPS are modelled and simulated. Also Senseo integration with Kalman Filter is realized. The GPS error is reduces from 10m to 1m.

8. Conclusion

The dynamics and behaviour of a multirotor vehicle is investigated using a test platform both for complete vehicle and single actuator part only. When modelling not only the vehicle but sub components are also being modeled. Motor-Prop-Battery power train is modeled. Single axis control and output is modelled. Sensor behaviour is investigated and modeled.

There are many papers focused on multirotors investigating different aspects. Many investigate mathematical model generally, however the sub parts and vibration effects of sub parts locally and overall are not well investigated. Many research papers investigate a preconfigured multicopter, however here we state that multicopter should be precisely designed according to payload and flight performance parameters required.

9. Literature

- [1] <http://diydrones.com/>
- [1] Michael A. Demetriou , Design Optimization of a Quad-Rotor Capable of Autonomous Flight, WORCESTER POLYTECHNIC INSTITUTE
- [3] Taner Mutlu, Chinghiz Hajiyev, Modelling And Integration Of Navigation Sensors, Xsemetro, Bueonos Aires, 2013
- [4] <http://geomag.usgs.gov/>
- [5] R. M. Rogers, "Applied Mathematics in Integrated Nnavigation Systems," American Institute of Aeronautics and Astronautics, 2000.

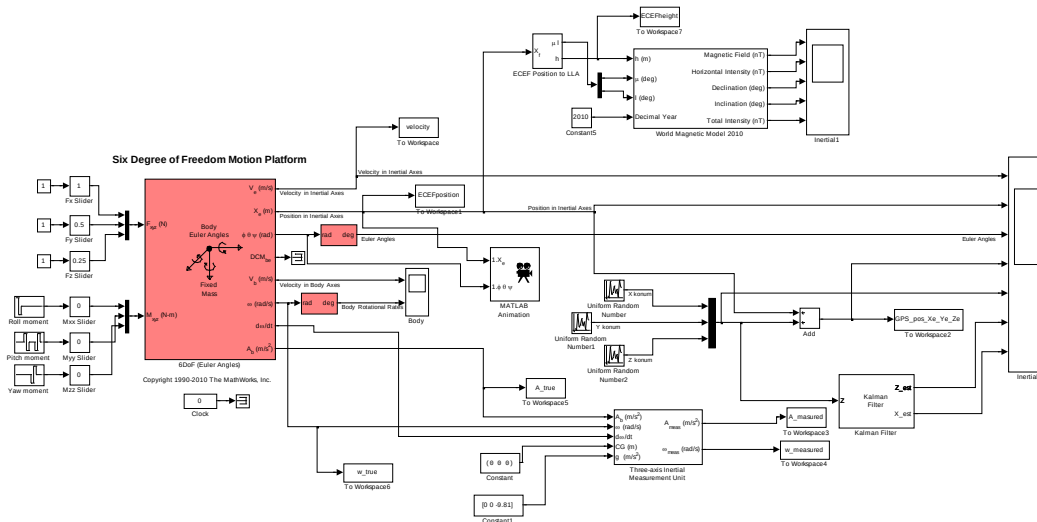


Figure 3 : Sensor Simulation of GPS, Magnetometer, Earth Magnetic Model and IMU

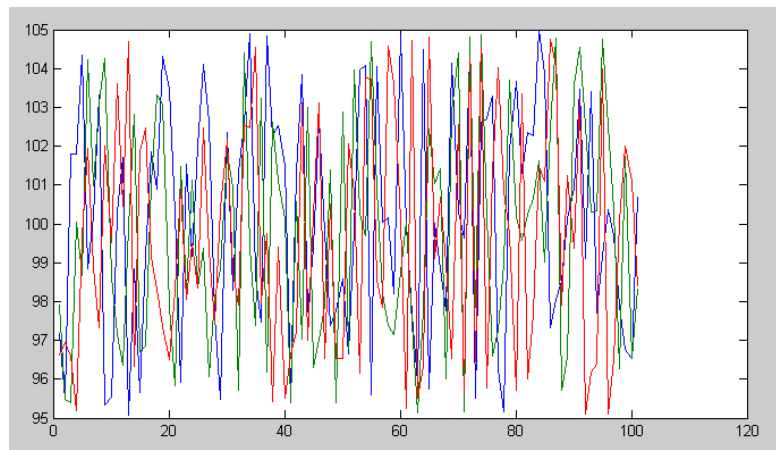


Figure 4 : GPS simulation results(+/-10m)

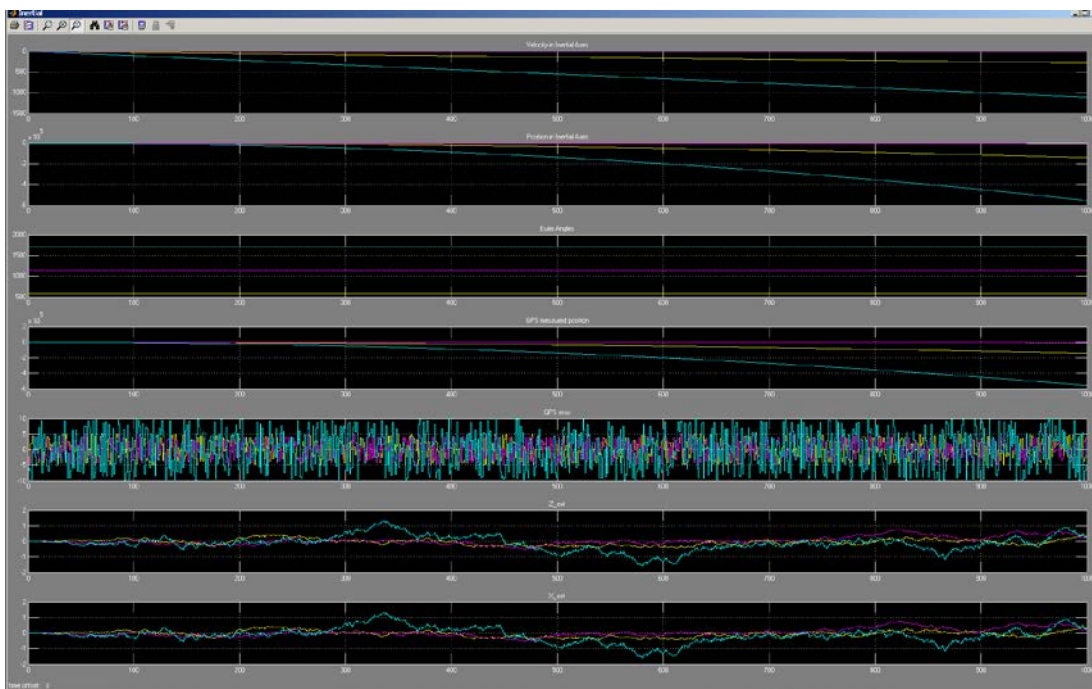


Figure 5: Inertial Axis velocity, position, GPS measurements, GPS real errors, and Kalman Filter estimation outputs are shown.

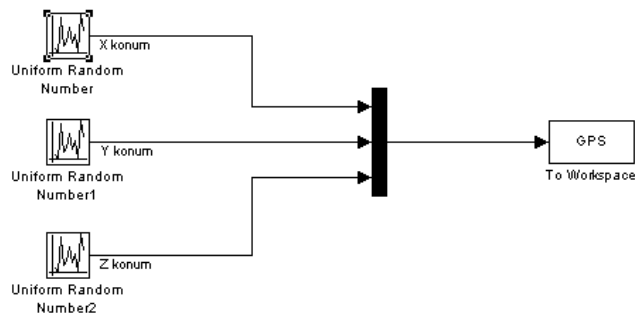


Figure 6 : GPS static position simulation

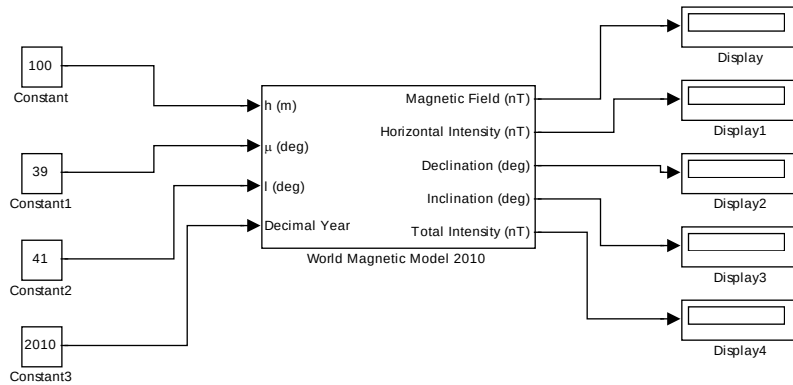


Figure 7 : Earth magnetic model simulation

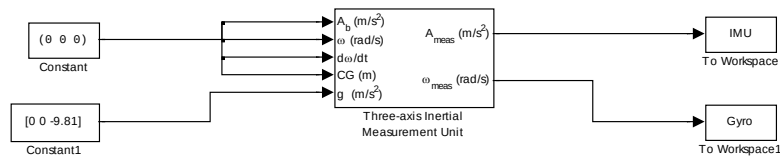


Figure 8 : IMU 6DOF simulation model

Table 1: Power train measurements

	Motor	Motor Weight(gr)	Propeller	Propeller Weight	Battery Voltage	Battery Weight(gr)	PWM(%)	Current(A)	Lift(gr)	Lift/Power Ratio
1	Sunnysky X4112	150	16x5	20	14.8	885	-	5	720	-
1	Sunnysky X4112	150	16x5	20	22.2	1300	-	5	920	-
1	Sunnysky X4112	150	17x8	70	22.2	1300	-	5	800	-
1	Sunnysky X4112	150	15x8	46	22.2	1300	-	5	900	-
1	Sunnysky X4112	150	15x4	22	22.2	1300	-	5	600	-
2	Multistar 390KV	102	9x6	16	14.8	885	50	1,78	164	-
2	Multistar 390KV	102	1238	20	14.8	885	50	1	156	-
2	Multistar 390KV	102	1238	20	22.2	1300	50	1	206	-
2	Multistar 390KV	102	9x6	16	22.2	1300	50	1	146	-
2	Multistar 390KV	102	17x8	70	22.2	1300	50	STOP	-	-
2	Multistar 390KV	102	15x8	46	22.2	1300	50	STOP	-	-

THE IMPACT ANALYSIS OF HYDROXIDE MIXTURE ADDITION ON THE COMBUSTION PROCESS IN THE DIESEL ENGINE.

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Abstract: This paper presents the analysis which is based on the parameters of the real device for producing a mixture of hydroxyl (HHO) and similar parameters to the real 2.0 SDI VW Golf MK V engine. Theoretical analysis has been made to principles of cooperation the engine with HHO's generator. The effects of the gas on the engine and operating economy were established. The analysis was divided into quantitative and qualitative. Quantitative analysis was contained the theoretical and economic calculation of the thermodynamic cycle taking into account the HHO gas. Qualitative analysis was concerned to the quality of combustion in the engine and the impact generator HHO to the quality of the combustion.

KEY WORDS: DIESEL ENGINE, COMBUSTION PROCESS, HYDROXIDE MIXTURE

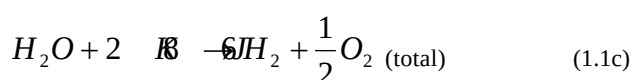
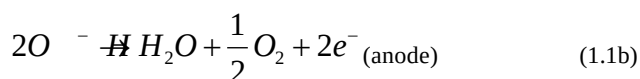
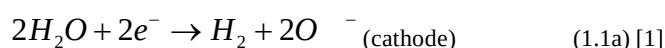
1. Introduction

High costs of fuel are essential stimulus for working not only over new fuels or engine constructions but also they are the urge for working over the modification of the combustion process by adding or changing the participation of air components in the working load of diesel engine. One of such solutions is adding of hydroxide mixtures produced in the electrolysis method. The present study is the introduction for breaking research carried out in Zakład Pojazdów Samochodowych i Silników Spalinowych (Cars and Internal Combustion Engines Plant) and it is also a theoretical consideration of this technology, which takes into account thermodynamics rules as well as economic issues.

1.1 HHO technology

The HHO technology is understood as a system connected to the sparking ignition or diesel engine where the stoichiometric hydroxide mixture called HHO gas is supplied into the suction collector.

HHO generator, which means water electrolysis cell, works on the basis of the following reaction:



This is the endothermic reaction in which electric energy is added in order to create oxygen and hydrogen. In the electrolytic cell, hydrogen is produced by cathode whereas oxygen by anode. Taking into account the characteristics of hydrogen, oxygen and

water and assuming that the energy comes from electric energy, the process goes adiabatically :

$$V_a = -\frac{\Delta H^o}{n \cdot F} = 1,4 \text{ V} \quad (1.2)$$

Thus the potential necessary for adiabatic process of the above mentioned reaction is followed by the pattern (1.2). Smaller potential than this will prevent the reaction process while bigger potential will cause heat production which results as a process loss. Therefore it follows that in HHO generator powered by car installations (V= 12V) there may occur quite intensive electrolyte heating which may cause exploitation problems and may cause significant losses so it is not beneficial in the area of thermodynamics.

2. Theoretical analysis

In order to analyze theoretical basics of engine with HHO generator operations as well as to estimate the impact of HHO gas on the engine work and profitability of exploitation the theoretic analysis was made. This analysis has been divided into quantity and quality one. The quantity analysis included theoretic calculations of the thermodynamic circle considering HHO gas and economic calculations. The quality analysis has described combustion in the diesel engines and, what is more, it tried to estimate the impact of HHO gas generator onto this combustion.

2.1 Analysis of thermodynamic circle

The analysis of thermodynamic circle has been made on exemplary slow suction diesel engine. Such an engine had similar parameters to SDI 2.0 engine in VW Golf MK V car working on the highest power, which performance without HHO system were known and could be compared to obtained results. The analysis has been made to check whether the introduction of HHO improves the thermodynamic efficiency of the circle without

consideration of improving the quality of combustion. Especially there was investigated if HHO, as neutral gas in the combustion chamber, which supplies certain amount of heat, has an impact on the thermodynamic circle.

The thermodynamic analysis was carried out by the use of patterns form [4] modified for consideration of the HHO impact as well as patterns based on one's own thoughts.

General assumptions

Sabath's Circle

The maximum pressure of combustion is the same with or without HHO.

HHO does not cause the growth of used heat factor.

HHO gas does not need extra oxygen for combustion.

Adding of HHO into the intake air causes the dilution of the intake air (more air is needed for combustion of 1kg of diesel oil) and it supplies additional thermal energy because of combustion itself.

In the consideration of the engine working cycle, it has been assumed that the whole volume of engine is in one cylinder. Thus at the end it was not necessary to multiply obtained values by the number of cylinders. The results together with used patterns are presented in the following table.

Table 2.1: The results of calculations and equations used for calculating the thermodynamic circle.

	Symbol	Equation	Value without HHO	Value with HHO
Density of sucked air	ρ_{pow}	$\rho_{pow} = \frac{1}{V_a}$	1,05kg/m ³	1,05 kg/m ³
Density of HHO	ρ_{HHO}	$\rho_{HHO} = \frac{P_1}{R_{HHO} T_s}$	0,33 kg/m ³	0,33 kg/m ³
Computational saltatory volume up to 1kg of diesel oil	V_s	$V_s = \frac{1}{1 - \%H} \cdot \frac{\lambda L_t' V_a}{H \cdot \eta_v O}$	26,13m ³	26,39m ³
Fuel value of HHO	W_{HHO}	$W_{HHO} = W_{H_2} \cdot \frac{2,0}{1,8}$	13,45 MJ/Kg	13,45MJ J/Kg
Fuel value of fuel considering HHO	W	$W = W_o + \%H \cdot \rho_v H \cdot (Q_c + QD) \cdot W_H$	41,90 MJ/Kg	43,13MJ J/Kg
Work of one cycle	Work	$W = \oint_{V_1}^{V_2} P k \cdot dV = \int_{V_2}^{V_4} P \cdot dV$	1696 J	1726 J

Heat provided in one cycle	Q	$Q = (W \xi \frac{V_2}{V_c})$	2566J	2614J
Efficiency of the thermodynamic circle		$\frac{Work}{Q}$	0,6614	0,6604
Work of one cycle for producing HHO	Work _{HHO}	$W_{HHO} = \eta_{HHO} \cdot \rho_{HHO} \cdot V_{HHO} \cdot W_{HHO} / \eta_{HHO}$	0J	154,50J
Work of one cycle with considering HHO generator	Work _{net}	$W_{net} = W - W_{HHO}$	1696J	1572J
Efficiency of the circle with considering HHO Generator		$\frac{Work_{net}}{Q_{ON}}$ Q _{ON} is the heat from combustion of oil	0,66	0,61
The use of fuel	$\dot{m}_{ON}$	$\dot{m}_{ON} = \frac{(Q_{ON}) \cdot 60n/2}{W_{ON}}$	7,72kg/hour	7,60kg/hour
Engine power	Power	$P = \dot{m}_{ON} \cdot W_{ON} \cdot \frac{n}{2 \cdot 6}$	59,39KW	55,02KW
Unit use of fuel	g_e	$g_e = \frac{\dot{m}_{ON}}{P_{OW}}$	0,130Kg/KW hour	0,139Kg/KW hour

3. Conclusions

The abovementioned calculations leads to several important conclusions.

Firstly, the theoretical result of power, 59.37 KW is pretty close to the actual 2.0 SDI engine power in VW Golf MK V car, which is 55 KW [6]. The fact that theoretical calculations show higher power is caused by the resistance and loses in the actual engine. However, the theoretical and actual convergence of the power confirms the assumptions of those calculations.

The most significant conclusion from those calculations is the fact that the adding of HHO gas does not improve the efficiency of the thermodynamic cycle in the diesel engine. Even without considering the energy necessary for producing HHO gas (which equals 0.6604), the efficiency of the thermodynamic circle is lower than the efficiency of the circle without HHO (0.6614). Considering the power needed for producing HHO the efficiency of the engine with HHO (0.57) is much lower than the efficiency without HHO

(0.66). The engine power is about 8KW lower and the unit use of fuel increases by about 6%. The increase of HHO amount does not cause any improvements of the efficiency of engine fed by HHO, while the decrease of HHO amount makes the performance of engines fed or not by HHO convergent. From what has been said it follows that adding of HHO has a negative effect on the thermodynamic circle since the HHO generation consumes profusion of power. Thus any improvements of engine performances must come from increasing of the heat use factor, which means the improvements of combustion quality of fuel-air mixture.

It must be noticed that in the present analysis HHO gas plays similar role to the fumes in the engines with EGR insulation as HHO is neutral gas which does not take part in combustion, except from providing heat. Nevertheless, in the case of ERG installation the neutral fume gasses work as cooling factor in order to reduce nitrogen oxides emission form fumes. Adding HHO gas, on the other hand, probably will increase the temperature of combustion.

4. Literature:

- [1] Lewandowski, Witold. M. *Proekologiczne odnawialne źródła energii*. Warszawa : Wydawnictwa Naukowo-Techniczne, 2012.
- [2] Tsiplakides, Dimitrios. *PEM Water Electrolysis Fundamentals*. http://research.ncl.ac.uk/sushgen/docs/summerschool_2012/PEM_water_electrolysis-Fundamentals_Prof._Tsiplakides.pdf. Pobrane 22 Marca 2013.
- [3] Website of HHO Plus Alternative Technologies Ltd. Company <http://www.hho-plus.com/>. Downloaded 13.03.2013
- [4] Wajand, Jan.A. *Silniki o zapłonie samoczynnym*. Warszawa. Wydawnictwa Naukowo-Techniczne, 1988.