

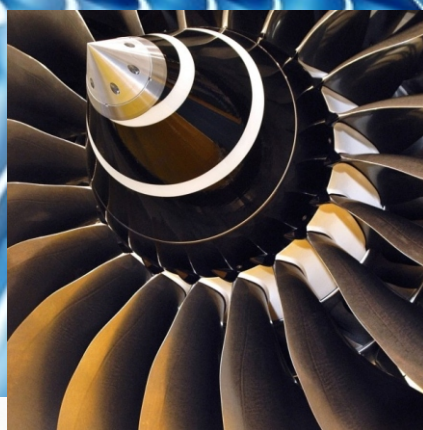
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DEVELOPMENT AND RESEARCH OF TEMPERATURE CONTROL SYSTEM OF A HIGH-VOLTAGE BATTERY OF A PERSPECTIVE ELECTRIC VEHICLE

РАЗРАБОТКА И ИССЛЕДОВАНИЕ СИСТЕМЫ ТЕРМОСТАТИРОВАНИЯ ВЫСОКОВОЛЬТНОЙ АККУМУЛЯТОРНОЙ БАТАРЕИ ПЕРСПЕКТИВНОГО ЭЛЕКТРИЧЕСКОГО ТРАНСПОРТНОГО СРЕДСТВА

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Abstract: The development of temperature control system of high-voltage batteries is an actual and important task in the development of modern electric and hybrid vehicles. There are a large number of designs and types of temperature control systems. In this article, we propose to consider a temperature control system based on a liquid cooling system and designed for both cooling and heating the battery in a wide range of ambient temperatures. In the development process of temperature control system for high-voltage batteries were carried calculations, 3D modelling of the design and tests.

Keywords: VEHICLE, ELECTRIC VEHICLE, TEMPERATURE CONTROL SYSTEM, COOLING SYSTEM, HIGH-VOLTAGE BATTERY

1. Introduction

The development of electric transport in the European Union has become one of the three priority areas of the European economy, and in Russia energy efficiency is declared the main direction of the country's development in the coming years. According to the forecasts of the Subcommittee on Strategic Innovations in the Automotive Industry of the Chamber of Commerce and Industry of the Russian Federation, by 2025 at least 50% of the world's produced vehicles will be on electric traction [1, 4]. Already, all major automobile plants are developing or producing such vehicles. Developments in the field of electromobility transport are engaged in the largest universities, scientific organizations, and enterprises of the Russian Federation. However, in our country now, electric vehicles is not very popular. This is due not only to the underdeveloped infrastructure, but also to climatic conditions. In the greater territory of the Russian Federation is prevailed the cold climate [3, 4, 5 and 6]. Studies show that the mileage of electric vehicles depends strongly on the temperature conditions of the high-voltage battery, which is one of the main elements of the functioning of such vehicles. At low temperatures, the mileage of electric vehicles falls sharply (to 30...40%), and at high temperatures, the high voltage battery can overheat, which can lead to degradation of battery cells. Thus, the task of thermostating high-voltage battery is very important for our country.

Consider the design of high-voltage batteries with thermostating systems of commercially produced vehicles on electric traction.

The Chevrolet Volt T-shaped lithium-ion high-voltage battery, shown in Figure 1, is installed under the car and passes through the central tunnel and under the rear seats.

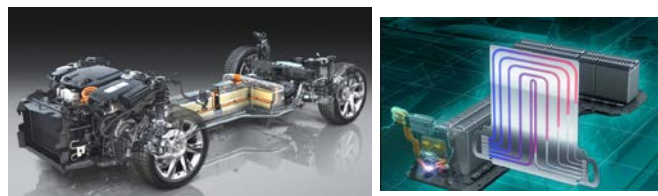


Fig. 1 T-shaped lithium-ion high-voltage car battery Chevrolet Volt with aluminum cooling plate.

Through the quick-release couplings, the coolant enters into the of the high-voltage battery. Inside the housing of battery, there are thermal channels that allow the coolant to flow through the cooling plates between the flat cells of the lithium-ion batteries. These channels allow cooling or heating of the cells depending on operational requirements. If the temperature of the battery is lower

than the operating temperature, the heating element located on the input channel of the cell is activated directly from the 360 V of lithium-ion battery.

The high-voltage battery of the hybrid Toyota Prius, shown in Figure 2, is located in the trunk above the rear axle of the car. Battery in the car has an air cooling. This type of cooling has a disadvantage, since in this case the air must be cleaned. Therefore, the battery is located inside the car and the air intake comes from the cabin.



Fig. 2 High-voltage car battery Toyota Prius.

The high-voltage battery of the Audi A3 e-tron PHEV-20, shown in Figure 3, has a complex liquid cooling system in which four cooling plates regulate the temperature of the eight modules. Cooling is carried out using a separate controlled low-temperature circuit. To warm up the battery using a thermoelectric heating element and gasoline preheater.



Fig. 3 High-voltage car battery Audi A3 e-tron PHEV-20.

The high-voltage battery of the Tesla Model S, shown in Figure 4, is arranged under the bottom of the car and consists of 16 battery modules with liquid cooling system. As a coolant in the cooling system, a solution of glycol is used. The battery module consists of a flat curved tube with battery cells, as shown in the figure, which evenly distribute the coolant between the cells. Further heat is diverted to the cooling circuit and is used by the climate system to heat the car's cabin.



Fig. 4 High-voltage car battery Tesla Model S.

Based on the analysis of the thermostating systems for high-voltage batteries produced vehicles, we can conclude that the liquid cooling system is mainly used. In addition, the thermostating system is influenced by the type and design of the battery cells used in the car.

2. Solution of the examined problem

Now, FSUE NAMI conducts research on the topic «Creation of new technologies and systems in the field of increasing the level of use of alternative energy sources for vehicles, based on the introduction of new scientific and technical solutions aimed at the use of electric and renewable (solar) energy for the movement of vehicles». As a model of an electric vehicle, the Russian electric vehicle LADA Ellada was used. This car uses the air-cooling system of the high-voltage battery (Figure 5) (the incoming airflow to the battery housing is supplied through the front bumper and radiator). On this vehicle, there is no battery heating system.



Fig. 5 High-voltage car battery LADA Ellada.

One of the main tasks of the project was the development of a high-voltage battery with thermostating system, which allows increasing the temperature range of vehicle operation and maintaining the temperature of the high-voltage battery in the operating range. The operating range of the battery cell without a significant decrease in its life 0 ... 50 °C. Such a temperature range is most suitable for the careful operation of the battery [2, 5, 7 and 8]. With the existing form of battery cells and the limited layout space, an air-water thermostating system for a high-voltage battery was developed. In addition, it was required to rework the concept of a system for the thermostating of a car. The result is shown in Figure 6.

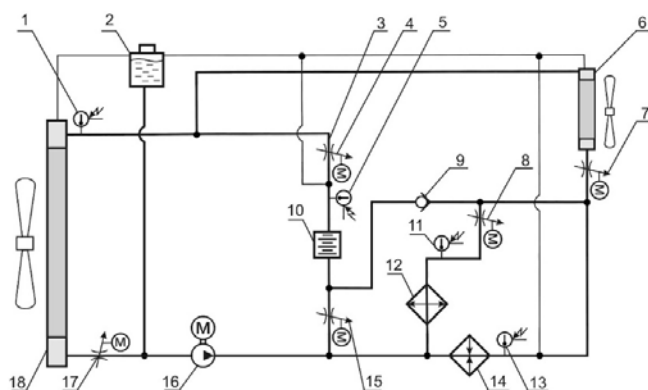


Fig. 6 Schematic diagram of the thermostating car LADA Ellada.

A schematic diagram of the car thermostating system comprises an electric pump 16 for supplying coolant from the radiator 18 along the pressure main to the housing of the high-voltage battery 10. To regulate the flow of the pump 16, the system has valves 4, 7, 8, 15, 17 with an electromechanical drive, which are controlled respectively by temperature sensors 1, 5, 11 and 13. The thermostating system has a cooler 12 and an electric heater 14, from where, depending on the operating mode (cooling or heating), the coolant flows through the check valve 9 to the battery housing 10 and then through the drain line 3 to the radiator 18. Also in the thermostating system there is a heater 6 and an expansion tank 2.

3. Results and discussion

The main stages in the development of a high-voltage battery with a thermostating system were:

- 3D modeling;
- calculation of heat and mass transfer.

Based on the car's engine compartment (Figure 7), and technical requirements for the high-voltage battery, it was decided to use 26 cells Winston WB-LYP90AHA as the battery cells.

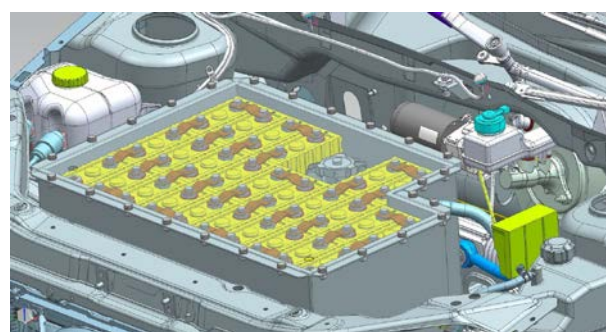


Fig. 7 The layout of a high-voltage battery in the car's engine compartment.

The high-voltage battery is a closed box with a thermal insulation layer, which significantly reduces the temperature effects of the environment. The housing of high-voltage battery has two sections. In the upper section, where the battery cells are located, there is a system of air circulation inside the closed volume (Figure 8). The movement of air inside the volume of the high-voltage battery is organized as follows. In the upper cavity of the closed volume, a depression is created, and in the lower cavity, a zone of increased pressure is obtained. These cavities are connected by channels formed by the shape of battery cells. The pressure difference is explained by the use of the fan SPAL VA32-A101-62S. The position of the high-voltage battery cells and the characteristics of the fan have been optimized to ensure sufficient air circulation inside the volume of the high-voltage battery.

In the lower section, there is a heat exchanger, which is a curved tube with many copper plates.

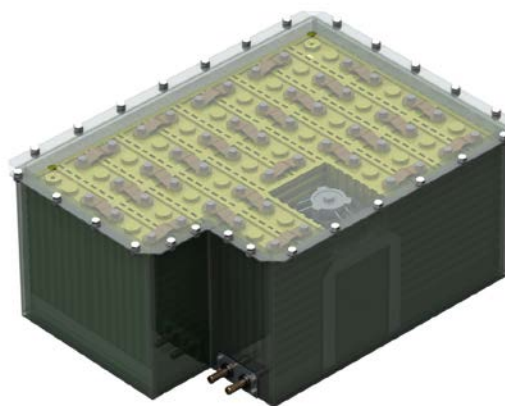


Fig. 8 3D-model of high-voltage battery.

The calculation of the efficiency of the system of thermostating of a high-voltage battery was carried out in two modes:

- 1) Loaded battery operation mode. The ambient temperature is + 40 ° C.
- 2) The battery is inactive. The ambient temperature is -25 ° C.

The main task of the calculations was to determine the flow rate and temperature of the coolant through the heat exchanger, to provide the target temperature values of the battery cells (0...50°C).

Figures 9-10 show the results of calculations for the first mode.

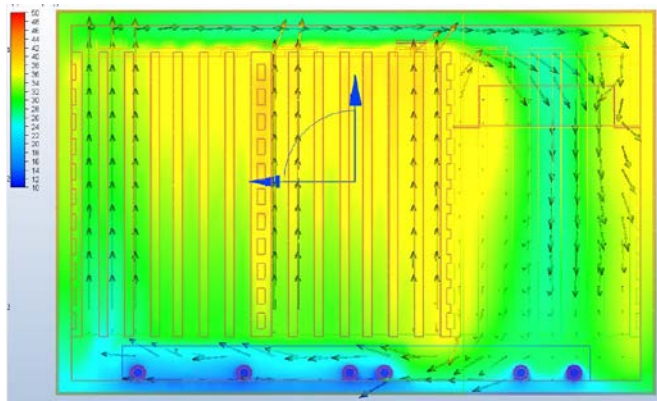


Fig. 9 Distribution of airflow and temperature in the battery.

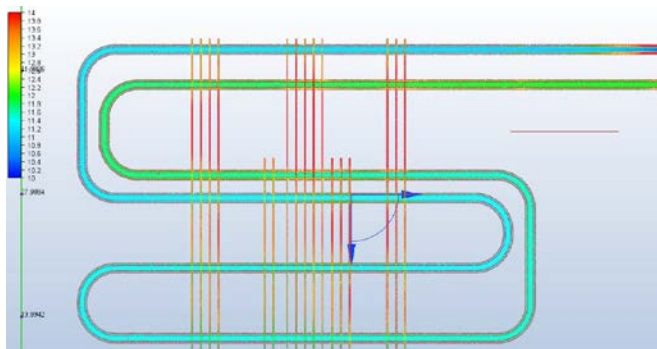


Fig. 10 Section through a radiator.

Figures 11-12 show the results of calculations for the second mode.

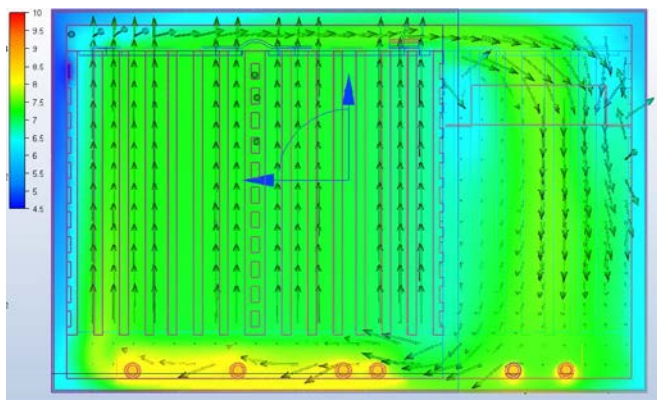


Fig. 11 Distribution of airflow and temperature in the battery.

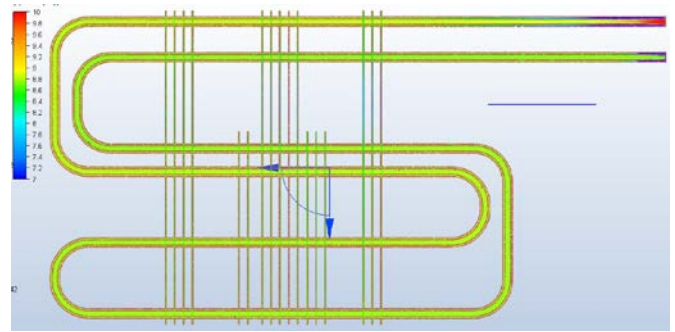


Fig. 12 Section through a radiator.

According to the figures, it can be seen that the developed thermostating system has optimal characteristics and allows maintaining the temperature inside the high-voltage battery within operating limits. This design of thermostating system of the high-voltage battery requires a small flow of coolant through the heat exchanger 3 l / min. The coolant temperature measured at the inlet to the heat exchanger + 10 ° C is constant both during cooling and heating. This shows a good level of thermal insulation of the battery volume from the environment.

After the manufacture of a high-voltage battery with a thermostating system, tests were carried out in the temperature test chamber of FSUE NAMI. Tests showed that in a loaded high-voltage battery at a temperature of + 40°C inside the temperature test chamber and a coolant temperature of + 10°C, which is supplied to the heat exchanger of the battery housing with a flow rate of 3 l/min, a temperature of + 49°C is maintained.

In turn, at a temperature of -25°C inside the temperature test chamber and a coolant temperature of + 10 ° C, which is supplied to the heat exchanger of the battery housing with a flow rate of 3 l / min, the cells of the high-voltage battery warm up above 5°C. This is enough for quickly heat the internal volume of cells of battery, safely activate the car and charge the battery when the car is parked.

A sufficient accuracy of the calculated results with the results of laboratory studies is obtained.

4. Conclusion

Currently, the car with a developed high-voltage battery with a thermostating system is preparing for road tests, which must confirm the effectiveness of the developed design.

This paper is made within the applied research under Agreement No. 14.624.21.0047 dd. 26 October 2017 for the following: "Creation of new technologies and systems in the field of increasing the level of use of alternative energy sources for vehicles, based on the introduction of new scientific and technical solutions aimed at the use of electric and renewable (solar) energy for the movement of vehicles" (unique project identifier RFMEFI62417X0047), made with the Ministry of Education and Science of the Russian Federation.

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VEHICLES FOR THE FUTURE – DILEMMAS AND PERSPECTIVES

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Abstract: The homeland of the first modern electrical car is Greece. Legendary **Enfield 8000** is one of the first electrical cars in the world, and that small two-seater was also extremely economical. It originated from the Greek island of Syros, where it is exhibited today at the Industrial Museum in Hermoupolis. It is believed that electrical cars are the real small revolution, because we replaced one type of engine with the other, while the autonomous vehicles resistant to human errors will represent the first real big transport revolution of the 21st century. Experts believe that new models of cars will have the best test in Norway¹, where during the last year drivers mostly (52%) voted for electric cars and hybrids. Electrified icons: Ford Mustang and Ford F-150 hybrids are coming by 2020. Porsche plans to sell 20,000 cars E mission per year. Also the French are planning to present 8 new electric cars (record holder is the model "zoe"², and soon the EV version of the "Quid", a small SUV that is sold on developing markets should join) before year 2022. In Serbia there is a plan to set up more charging stations for electrical vehicles. It will be initially only 3 stations within the project "Green Balkanica", while it is cited that in China there are even 5 million of these stations.

Keywords: ELECTRICAL CAR, FUTURE, ECOLOGY, SERBIA, WORLD.

1. Introductory considerations

Would you be in a car that is driving instead of you? Many car manufacturers and other companies that are not part of the auto industry, have been working on the development of autonomous vehicles for years. So far they have mainly been focused on solving the problems that may occur when these cars find themselves in real traffic conditions and did not think too much about the future customers and their attitudes towards self-driving vehicles.

Real struggle is led in the world for new technologies between China and the United States, i.e. the race to develop the first "egzaskeji"¹ computer, as previously Russia and the United States fought for the development of space technology. The biggest problem in its development will be to ensure sufficient electricity, because its work requires the capacity of a small nuclear power plant. We should mention the supercomputer "Sunway TaihuLight" and computer "The Summit". Building the "Summit" America could for the first time after year 2013 again take over the primacy in the development of supercomputers. China then launched the computer "Tianhe-2" and took over the primacy in the development of the fastest computers in the world. In this race participate also Japan and the European Union (EU) and promote the development of various scientific disciplines, industrial technology, defense.

According to the data of "France Press" the European Automobile Manufacturers Association (ACEA) announced that in March 2007 in EU the number of registered passenger cars increased by a significant 11.2%. Today, the European car market is growing² and returns to the level before the economic crisis of 2008.

The question is "if your vehicle is fully autonomous (there is no steering wheel or steering commands) do you need auto insurance? Do you need a driver's license? Are you responsible in the event of a collision, or the manufacturer? Should a car manufacturer or its owner have insurance in the case of an accident? Should the liability coverage be included in the purchase price of the car? These are important legal issues that need to be answered.³

Greece is the home of the first modern electric car. Enfield 8000 was one of the first electric cars in the world, and a small two-seater was also extremely economical. It is interesting that it just originated at the Greek island of Syros (Syra island archipelago), where it is exhibited today at the Museum of Industry in Hermoupolis. The owner of the British company Enfield Automotive, Mr. Janis Goulardis in early seventies, contacted Mr. Jorgos Mikhail who was dealing with the construction of space shuttles for NASA. Specifically, he wanted that the first electric car is produced just in Greece, but its further production will take the company Enfield in the UK. For the Greeks themselves was of the great importance to continue the relationship with the company of Goulardis in Britain since it is precisely the one that produced vehicles used for the struggle against the Germans in the Second World War.

A small car was great and the most convenient discovery for the time when it was manufactured as evidenced by the interest in it from the whole world. A small two-seater battery was more popular beyond the borders of Greece, especially in London, where its 123 copies were sold, a few hundred were also sold in Sweden, where it was used as the primary mean of transport in the mines. Automobile worked on eight batteries and after seven hours of charging it was able to hold out the next 24 hours. It reached speed of 80 kilometers per hour and it was perfect car for the city in which it ran about 70 kilometers daily.

2. Serbia and World Experience

"Superchargers" connections that fill in "Tesla" vehicles in six countries of South-Eastern Europe by the end of 2017 have been set in our country at three locations: - near Belgrade, - Požega and - the city of Niš. The founder of the "Tesla" expects that fully autonomous "Tesla" will be ready in 2018, but it is clear that legal approval will take another one to three years more. Meanwhile the first electrocharger started to work on Corridor 10, and in Serbia the first device for charging electric cars began to work at the toll station of Preševo, on the border with Macedonia. Testing has shown that it works excellent and that it is possible to simultaneously charge three cars.

The production of the new "Fiat 500 L" has started on 25th of May 2017 year, and it is the best-selling model in its category in Europe. About 40% of built in parts are new. On one chassis can be made at least four models, and Italian partners are trying to keep the Serbian car factory from Kragujevac under its auspices mostly because of cheap labor. Unfortunately, the wages of workers in

¹ China has announced that this computer will be completed by 2020.

² Better results were observed in all 5 major markets, so that in March in Italy, the number of newly registered cars increased for 18.2%, in Spain for 12.6%, in Germany for 11.4%, in the UK for 8, 4% and in France for 7%. /Tanjung/

³ Poitras Colin, The rise of self-driving cars, March 2017. <https://phys.org/news/2017-03-self-driving-cars.html>

factory based in Kragujevac and today are 3-4 times lower than those of "Fiat"'s workers in Italy, Turkey and in Brasil. The term contract of Italian-American group "Fiat-Chrysler" with Serbia for 10 years expires at the end of year 2018. It is believed that the car factory in Kragujevac can not survive if we do not produce a totally new car soon.

For the first time in March 2015, the autonomous car drove from San Francisco to New York. Mining company "Rio Tinto" already operates a fleet of self-driving garbage trucks in the mine in Western Australia.

During the spring 2015, the Federal Department of Environment, Transport, Energy and Communications

in Switzerland has given permission to the company "Swisscom" to test "Volkswagen Passat" without a driver on the streets of Zurich. But still "Volkswagen" remained the largest European manufacturer with regard to the new registrations of its "BMW", "Audi", "Porsche", "Seat" and "Scoda," there is an increase of 6.5%, so that this manufacturer dominates on the market with a share of 21.3%.

Since the summer in 2015 the French Government allowed to "Peugeot Citroen" to perform testing under real conditions in the area of Paris. These experiments were extended to other French cities such as Bordeaux and Strasbourg in 2016, and the first demonstration of autonomous vehicles on the open road in France was performed in Bordeaux in October 2015. Also, the French are planning to present 8 new electric cars till 2022-year. (Record holder is model "Zoe" and very soon the EV version of "Quid", an small SUV, that is sold in developing markets should join.) In mid-October 2017, the French car company "Renault" published that half of its models will be hybrid or electric till 2022. These "robotic" vehicles will have an elevated degree of autonomy and "Renault" will offer 8 fully electric and 12 hybrid vehicles before year 2022 and strategic plans anticipate the doubling of vehicle sales in the markets of Russia and China.

At the end of October 2017 it was announced that it was a successful first testing of vehicles in Bavaria, i.e. smart bus without the driver was the first pickup truck without driver⁴ presented by the German railway "Deutsche ban". And related to railroad, probably that is why once is said that where there are no trains - there is no life. The testing was conducted in the spa Bad Birmbach, in Bavaria on the south of Germany, and this electric mini bus can carry 12 passengers and represents a new era of public transport. So the first public transport line with autonomous vehicles was opened. Since 2018, "Deutsche ban" who founded the branch "Joki" dedicated to electric mobility and transport of the future, intends to test his pickup truck in several German cities, including Hamburg, Paris, Lyon, Las Vegas and Dubai already have such vehicles, but in smaller proportions. The new German law also contains a special provision that allows for self-driving cars in certain limited areas, such as parking areas in shopping malls.⁵

Company "NuTonomy" is planning to place commercially self-driving taxis in Singapore during 2018, with the intention to be operational with the fleet of self-driving taxis in 10 world cities till

2020. Electrified icons: Ford Mustang and Ford F-150 Hybrids are coming by 2020 and Porsche plans to sell 20.000 mission E cars a year.

"BMW" has already announced that by 2025 it is planning to put on the market 12 electric models and 13 versions of hybrid cars. The first "BMW" electric car "mini" will come off the production line in year 2019, according to the report of the British public Service BBC. "General Motors" is testing 50 self-driving vehicles "Chevrolet Bolt Sedan" in several states including California and Michigan.

During January 2018 in town Jeddah (Saudi Arabia) was opened the first Car Show dedicated to women – customers. Also manufacturers have prepared many novelties for Geneva Motor Show, the most influential automotive event in Europe on the 8th of March 2018. Thus, in "Mercedes" A class now new trunk will be larger, of 370 liters and aerodynamics and performance have been improved. While the "Opel" will not show up at this event in 2018, "Škoda" has prepared redesigned "Fabia" which is improved and with a screen of 6.5 inches impresses at first glance. Sales of this model should begin in mid-March this year. It was expected that the "Hyundai" in Geneva exposes the fourth generation of the car "Santa Fe" with more modern design.⁶

Romanian brand "Dacia" continues to develop under the control of "Renault". This reliable and safe car, "Duster" got all it could from the "Renault" and "Nissan". But also the leaders in the "Maserati", who were planning that SUV "Levante" becomes a pillar of financial stability of this Italian brand, have failed, during the 2017 production has been stopped for several days due to the weaker demand. "Fiat-Chrysler cars" will reduce working hours until June 2018 and the factory "Mirafiori" will produce less "Levante". Yet the contracts of solidarity for workers were introduced, so workers will not receive temporary layoffs, but they will be earning less. Thus, a little more than 2000 jobs have been rescued.

3. Importance of Safety Issues

Industry of self-driving cars has experienced that regulators prevented innovations that could improve public safety. In the USA, 30 000 people die every year on the roads, and over a million are injured. 94% of these accidents are caused by human factor.⁷ Self-driving cars could eliminate human error as the cause of 90% of collisions and they could make people more mobile, may be reduce emissions and set in motion economy.

These days in Serbia new stricter regulations on traffic safety were adopted. Harsher penalties are provided for speeding and also the mandatory installation of video surveillance during the inspection, which will be associated with the Ministry of Internal Affairs by a special program, is predicted.

During July 2017 year more than 5.3 million vehicles passed along highways in Serbia. (statement of the Public Enterprise "Roads of Serbia"). Unfortunately, there are also thefts⁸ of traffic

⁴ This pickup truck was projected by the French start-up company „Easy mail“.

⁵ See: Hetzner C, "German industry welcomes self-driving vehicles law", Automotive News Europe, May 15, 2017, <http://europe.autonews.com/article/20170515/ANE/170519866/german-industry-welcomes-self-driving-vehicles-law>, 22.09.2017.

⁶ Koreans have changed the interior and set a high central touchscreen.

⁷ Draxler B, Who's Responsible When A Self-Driving Car Crashes ? June 2015, Bryant Walker Smith talks shop, <https://www.popsoci.com/whos-responsible-when-self-driving-car-crashes>

⁸ About 120 million dinars or around one million euros.

signs and other traffic signalization and equipment along our roads, and that directly reduces security and directly endangers the lives of participants in traffic.

At the same time the authorities in France have decided to tighten laws on road safety, all in order to help reduction of the number of fatalities on the roads and improve safety. So in the future the drivers will not be able to stand on the side in order to check the phone⁹; even though the engine is shut down. If drivers are caught by the authorities with a mobile phone in their hands, for that they will pay a fine of 135 euros. The law now provides for an obligation for the driver to park the vehicle in the parking place, turn off the engine and then check the mobile device.

And in China at every more significant crossroads in Beijing, the teams of emergency services are stationed and ready to react in the case of traffic accidents. Traffic violations are charged for immediately after the execution, on-site, and police has devices in which data of the offender are entered and issues the proof of payment of such penalty.

Researchers from the Serbian Institute of Nuclear Energy "Vinča" in cooperation with colleagues from the Croatian Institute "Ruđer Bosković" and the Swiss Federal Institute EMPA already for two years are working on the project of hydrogen energetics with the title "New materials for saving energy." It is about development of methods for storing hydrogen that would be applied as fuel and energy source. The authors develop complex hybrids (which contain large quantities of hydrogen) capable of releasing or receiving hydrogen according to our need.

In the final version of the Climate Action Plan, the Government in Germany lowered the aims on reducing emissions of carbon-dioxide for industrial sector, however, the industrial sector calls for reducing carbon dioxide emissions for only 20% by year 2030, comparing to year 2014.

It is stated that "Audi" is buying the technology for cars using hydrogen. "Numbers are the language to confirm the truth." From the company "Folkswagen" we are notified that Germany should reduce subsidies for diesel cars and ban vehicles that are big polluters. It is also pointed out that the gradual tax relief should be directed towards the promotion of environmentally friendly technologies. The scandal that broke out in 2015 indicated that the diesel cars of this manufacturer are to blame for the problems of air pollution in Germany and abroad. Calls for a ban on diesel cars already have full support in some major German cities.

The wider European project Central European Green Corridors (CEGC) included Slovakia, Germany, Austria, Croatia and Slovenia where the dense network of 115 modern fast chargers for electric cars was placed.

4. Conclusion

The first modern electrical car was great and the most practical discovery for the time in which it was produced what testifies the interest in it from the whole world. It is believed that electric cars are the real small revolution, because we replaced one type of the engine with another, while the autonomous vehicles resistant to human errors will represent the first real big transport revolution of the 21st century. Be ready for any surprise - it is a sign of culture, wrote the Indian philosopher and poet Rabindranath Tagore.

Having in mind that electric cars have become our future, on this path Serbia is still lagging behind, but on the way of electrification the most advanced is Scandinavia, especially Norway. The primary objectives are of economic - environmental nature with regard to electrical vehicles which produce significantly less carbon dioxide and in Serbia the setting up charging stations for electric vehicles is planned. As it was mentioned the first electrical charger on the Corridor 10 started to work, i.e. in Serbia the first device for charging electrical cars began to work at the toll station of Presevo, on the border with Macedonia. It will be initially only 3 stations within the project "Green Balkanika", while the cited data show that China has even 5 millions of these stations.

Expecting news from the area of self-driving cars this paper represents my contribution to the vehicles for the future for the generations to come.

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3. Poitras Colin, The rise of self-driving cars, March 2017, <https://phys.org/news/2017-03-self-driving-cars.html>

⁹ The only exception is in the case of a traffic accident or some similar situation when the use of a mobile phone is allowed, in order to realize an urgent call.

THREE-DIMENSIONAL SIMULATION OF THERMAL STRESSES IN DISCS DURING AN AUTOMOTIVE BRAKING CYCLE

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Abstract: In this study, a 3-Dimensional finite element simulation of a braking cycle including braking and cooling steps is presented. In order to induce thermal stresses, thermo-mechanical material behaviour and interactions between pad and discs are considered in the simulation. The results reveal that compressive and tensile stresses are happening in the braking and cooling steps respectively. Cyclic tensile stresses in the disc of heavy trucks would lead to the initiation of superficial radial cracks in them. The occurrence of hot spot phenomenon in the discs are also observed and discussed thoroughly. The proposed model could be utilized to estimate fatigue life of the braking discs in the automobiles and heavy vehicles..

Keywords: AUTOMOTIVE BRAKING, FINITE ELEMENT METHOD, THERMAL STRESS

1. Introduction

The components of duty vehicles such as trucks, due to their heavy weights endure large mechanical loads during their life-span, hence a proper maintenance and repair of them is essential. Brake disks, for instance, goes through very large braking loads which consequently shorten its life-time. Due to the friction on the contact surfaces of the pad and disc, kinetic energy of vehicle transforms into heat¹. A great deal of the heat is transferred to the brake system components. Therefore, the components of brake system would be exposed to high temperatures, leading to less favorable conditions for brake system such as reduction of friction coefficient, plastic deformation of disc, and thermal cracking in disc surface which subsequently weakens braking performance. Moreover, variations of stresses and strains during the cyclic heating and cooling cause the initiation and growth of cracks on the surface of brake discs². Hence, calculations of temperatures and thermal stresses during a braking cycle are very important for design and improve of brake system³.

Due to the overheating in the friction surfaces, deformation occurs in the discs and results in the change of contact state, so it leads to a local temperature increase (which is known as hot spots and hot bands in the literature)⁴. Therefore, in order to have more accurate predictions, the temperature and stress fields must be considered simultaneously. Fig. 1 shows a sample of thermal cracks on the brake disc surface after several hard braking cycles.



Fig. 1 Radial thermal cracks due to hard braking in heavy vehicles¹.

In order to solve the coupled field problems like temperature and stress in disc brakes, generally there are two ways: sequential coupling and direct coupling. Most of previous studies considered friction heat as a prior known heat flow over the contact surface, so as to save on computational costs and avoid complexity in the simulation. For example, Gigan⁵ studied a non-rotational heavy vehicle brake disc with a non-uniform heat flow distribution over the surfaces. However, their results were slightly different from the experimental observations. Some researchers are also using three-

dimensional models to simulate uncoupled temperature and stress fields, resulting in less accurate solutions due to the nonlinearity and large displacements during hard braking⁶.

The explicit coupled temperature-displacement algorithm is used in this paper, as the closest module to the real situation in hard braking.

2. Simulation

Geometry: a straight vaned type of commercial heavy vehicle brake disc is chosen to be studied here which consists of a hat, a neck, and two friction surfaces. Simplified cross-section model of a commercial truck brake disc is shown in Fig. 2. It has 36 straight vanes, each acquire an angle of 3 degrees, and spaced every 7 degrees in a 360 degrees cycle. Total thickness of discs is 48mm which includes two frictional surfaces along with a 18mm space for ventilation. Outer radius and inner radius of discs are respectively 218mm and 128mm. Each radial vane has a 77mm length. Overall dimensions of the disc and pad are summarized in Table 1.

Table 1: Overall dimensions of brake disc and pad

Item	Disc[mm]	Pad[mm]
Height	45	15
Inner radius	128	134.5
Outer radius	218	211.5

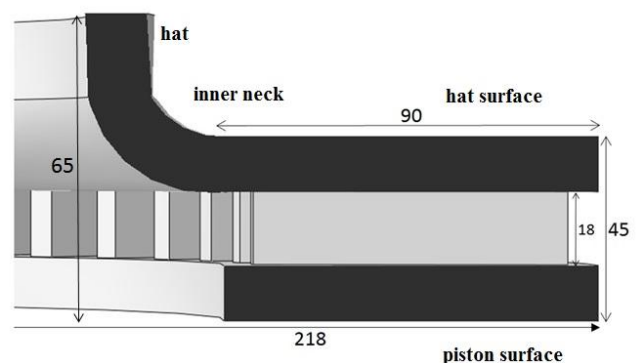


Fig. 2 Cross-section of a brake disc.

A longitudinal cross-section of brake pad and its dimensions are shown in Fig. 3. The pad is covering 60 degree of disc surface. Modelling of brake disc associated with brake pad is carried out in ABAQUS finite element commercial software.

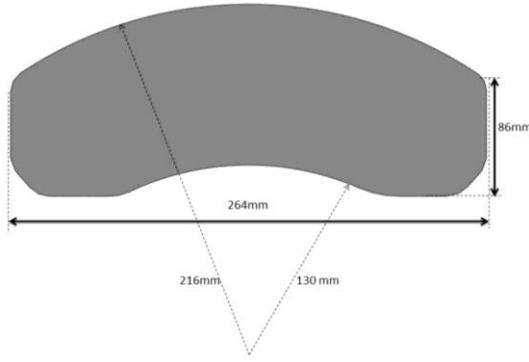


Fig. 3 Brake pad geometries

Mesh: A sample of mesh generation for the assembled brake disc and pads is shown in Fig. 4. The utilized element for the mesh is C3D8T type with a size of 3-4mm.

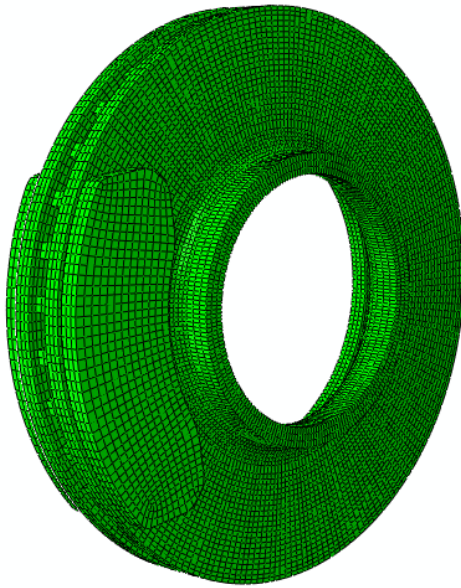


Fig. 4 A sample of mesh generation for brake disc and pads

Material model: Thermal properties of the pad, made from organic friction materials, is given in Table 2³.

Table 2: Brake pad material properties³

Item	Brake pad
Young's modulus(Gpa)	28
Poisson's ratio	0.29
Density(Kg/m ³)	2700
Conductivity	2.36
Specific heat	4000

Thermal diffusivity and the thermal conductivity are important material parameters for heat transfer in brake discs. Brake rotors in trucks, compared to passenger cars, are subjected to larger amounts of stresses, so they require materials with high thermal fatigue strength. Besides, high strength and durability is necessary to withstand high torque loads during braking. On the other hand, high thermal conductivity helps quick transportation of frictional heat away from the frictional surfaces. The studied brake disc is made of grey cast iron with a pearlitic microstructure. Grey cast iron is widely used as truck brake disc material because of its superior thermal fatigue strength, low squeal and good wear resistance which is important for a safe performance during its life time. Table 3 shows temperature-dependent parameters of brake disc material⁴.

Table 3: temperature-dependent parameters of brake disc material⁴

Parameter	25°C	100°C	200°C	300°C	400°C	500°C
Young's modulus[GPa]	101	98.5	96.8	96.3	81.3	80.3
Poisson's ratio	0.3	0.3	0.3	0.3	0.3	0.3
Density[Kg/m ³]	7293	7272	7243	7213	7182	7152
Conductivity [W/m.°C]	53.2	51.3	47.1	42.9	39.1	36.2
Specific heat [J]	488	532	563	599	631	669
Expansion [1/°C]	1.22e-5	1.26e-5	1.31e-5	1.37e-5	1.39e-5	1.4e-5

Plastic hardening model used in this paper is a non-linear kinematic, isotropic one. Table 4 shows material constants for the prediction of plastic hardening in the brake disc material.

Table 4: Material constants of plastic hardening model for brake disc material

Temperature	C ₁ [GPa]	Gamma ₁	C ₂ [GPa]	Gamma ₂
25	98.5	627	368	9220
300	95.5	607	361	9390
400	79.5	546	341	9690
500	60.2	474	319	101000
600	41.5	417	270	111000

Boundary Conditions: Different types of braking are defined, three types of which are explained here. In “stop braking”, the initial angular velocity of the brake disc is a predefined value and would be reduced to zero through a constant or non-constant deceleration. Another type is the ordinary braking, known as “snub braking”, where speed is decreased to a certain value (for safety reasons, e.g. speed control limits). The last one, “drag braking”, also known as “downhill braking”, is the use of brakes for preserving a specific speed while moving downwards a hill.

The third type is the one used in this paper due to its frequent repetition in heavy trucks. Moreover, initial temperature of the brake disc and pads is assumed to be 25°C. The speed of vehicle is assumed as 80 km/h which results in a constant angular velocity of 425r/min (44.46 rad/s) on brake discs during 10 seconds of braking cycle. A brake cycle is composed of two parts: A 10 seconds of uniform braking, and a cooling phase assumed to be 300 seconds (5 minutes). The following assumptions are made in the modelling of brake rotor in the finite element simulation:

- 1- Brake pressure is uniformly distributed all over the back side of the pads.
- 2- Friction coefficient remains constant during a braking cycle.

Table 5 illustrates braking parameters used in this study. A schematics of prescribed boundary conditions are also depicted in Fig. 5.

Table 5: Braking parameters

Braking time (s)	10
Braking pressure (kPa)	1000
Disc brake rotational velocity (rad/s)	44.46

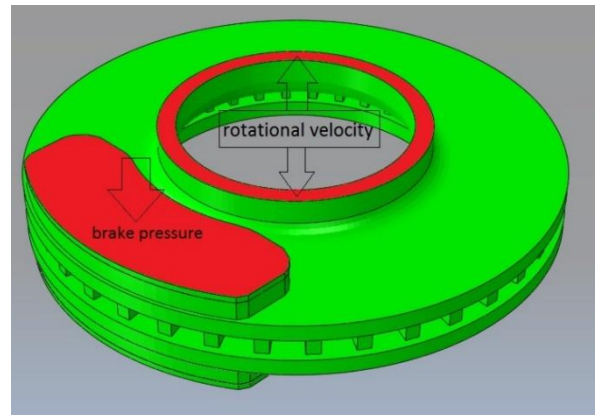


Fig. 5 Schematics of prescribed boundary conditions

In order to simulate a more accurate solution for the cooling process of the brake system components, both convection and radiation are accounted. Convection coefficient is computed in [7] for various brake disc velocities. Fig. 6 illustrates heat transfer coefficient at brake disc surfaces in terms of temperature, while the vehicle has an 80 km/h speed. As can be seen, convection coefficient increases gradually by the rise of temperature.

Since temperature is different on various sides of disc surface, for gaining a more reliable solution, the surface of disc is partitioned to three sub-region; each has a different value of convection coefficient (see Fig. 7). In order to use a constant coefficient value on both sides of the disc, Bio number must be less than 0.1.

Bio number is determined as $Bio = h \cdot L / k$, where h is the heat transfer coefficient, L is the characteristic length (or thickness of frictional layer), and k is the thermal conductivity of the material.

Using the thickness of each piece of brake disc ($L=13.5\text{mm}$) and temperature-dependent values of h and k , it would be determined that for a temperature range of $[25^\circ\text{C}-800^\circ\text{C}]$, Bio number would be less than 0.1, thus a constant value of convection heat transfer coefficient can be used for solving the cooling phase of brake cycle.

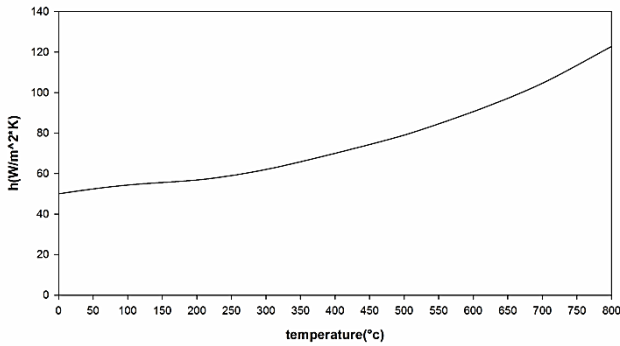


Fig. 6 The variation of convection heat transfer coefficient in terms of temperature at 80km/h

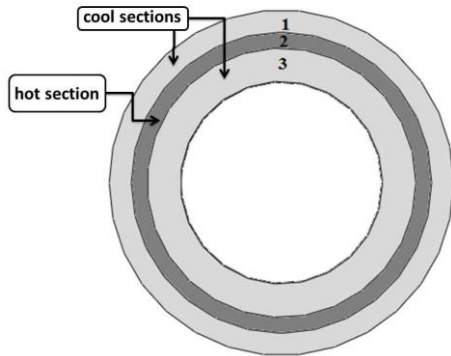


Fig. 7 Three defined regions of brake disc surface for convection

3. Results

Variation of stresses in braking and cooling phases of a brake disc would be presented and discussed in this section. Fig. 8 (a) shows the temperature distribution of front and back surfaces of brake disc during braking cycle. As can be seen, the temperature field is not symmetrical on both sides of the disc. Maximum temperature of the surfaces appears to happen in the inner ring of the frictional region, while maximum temperature of the back frictional surface occurs in the outer ring. Due to the cross-displacement of the neck and hub, known as coning, the contact conditions on both sides of the rotor would not be similar to each other. In addition, non-friction region almost has no temperature elevation. As can be seen in Figure 8 (b), it is clear that temperature distribution on the surface is non-constant, so that a non-uniform wear occurs on the pad and leads to an overheat on the pads.

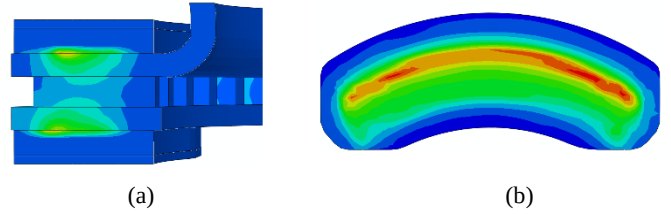


Fig. 8 Temperature distribution on a) a cross section of brake disc and pads at the end of braking (10s) and b) the surface of pad at the end of braking (t=10s)

Fig. 9 shows a cross-section of disc in addition to a series of points in radial direction, named as path-1. Temperature diagram over path-1 at different moments, i.e. 2, 4, 6, 8, and 10s, is shown in Fig. 10. As can be seen, initially the temperature in all points is equal to 25°C (room temperature); during the braking, it rises non-uniformly. Hence, the temperature on a specific radius of the brake disc surface would be maximum and is called a hot band in which it is most likely for fatigue cracks initiation over the surface of brake discs. Schematics of hot bands formation according to the pass of time is shown in Fig. 11.

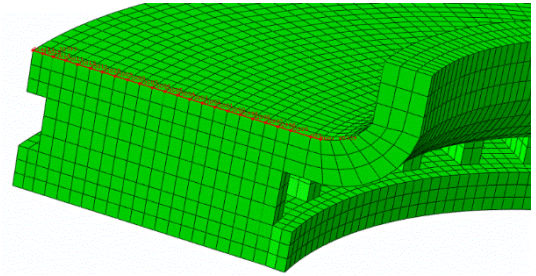


Fig. 9 Cross-section of brake disc and the definition of path-1 (red dots)

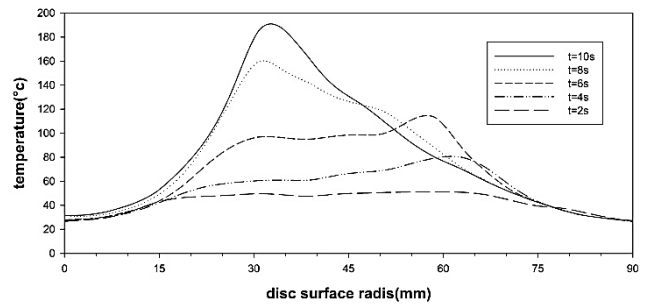


Fig. 10 Temperature diagram over the surface path-1 at $t=2,4,6,8,10\text{s}$

Circumferential stresses, also called hoop stresses, are the main component of developed thermal stresses, the variations of which during braking and cooling cycles would be the major cause in the initiation and propagation of surface radial cracks. As can be seen in Fig. 12, at the first couple of seconds in braking cycle, the distribution of circumferential stresses is relatively uniform, due to the uniform distribution of braking pressure and temperature over the frictional surfaces. However, over the time, coning on the hat of the disc leads to a non-uniform distribution, creating hot bands and hotspots on the surface. After 6s of braking, a hot band of frictional heat causes an intense change in the hoop stresses.

Distribution of circumferential stresses on the upper surface of brake discs is shown in Fig. 13. As can be seen, while at 10s the highest compressive stresses have been occurred in the location of hot band, proceeding to the cooling cycle ($t=300\text{s}$), the same place undergoes the highest tensions. This phenomena results in the initiation of cracks in the hot bands.

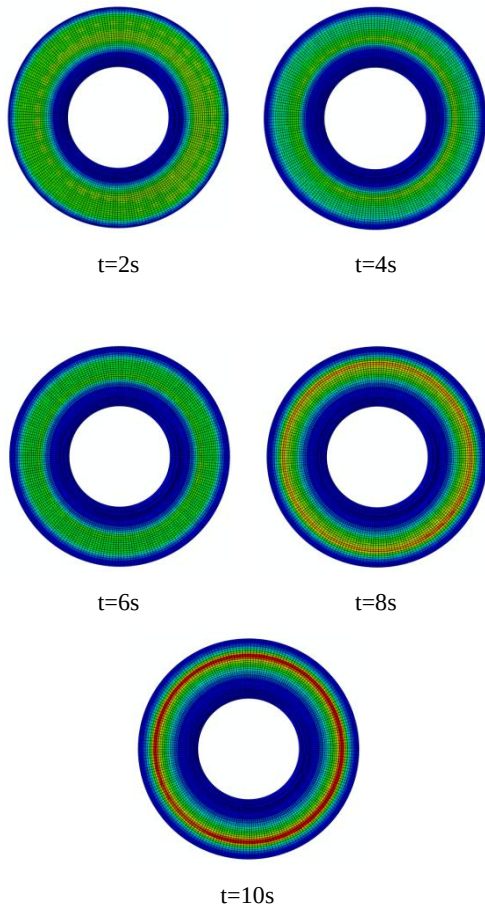


Fig. 11 Schematics of hot bands formation by passing the time (hot bands are depicted in red)

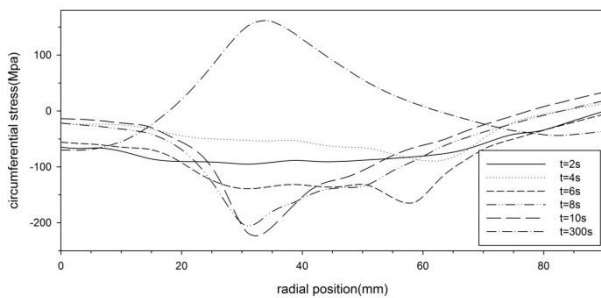


Fig. 12 Circumferential (hoop) stresses over the path-1 at $t=2,4,6,8,10s$

4. Conclusion

In this paper, a three-dimensional simulation of a braking cycle (including braking and cooling) carried out which causes high circumferential cyclic thermal stresses in brake discs. The simulation identified that the interaction of frictional heat generation, thermal distortion, and effect of coning in brake disc would create a “hot band”, which occurs at the working-surface of the disk. Moreover, the results show that critical stresses also occurred in the hot band. Therefore, the model used in this paper can be further used for examination of the geometry and material developments as well as fatigue analysis.

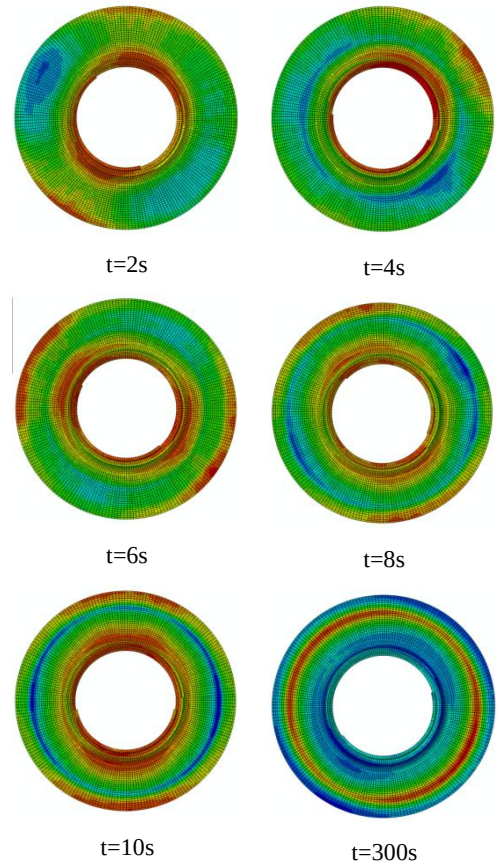


Fig. 13 Circumferential stresses for brake disc surface at $t=4, 6, 8, 10, 300s$

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COMPARISON BETWEEN THE PURSUIT GUIDANCE AND THE PROPORTIONAL NAVIGATION GUIDANCE LAWS REGARDING A PREDETERMINED SCENARIO

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Abstract: In tactical missile design, it is highly crucial to select the proper guidance method in order to meet the scenario requirements. As it is applicable in every aspect of life, trade-off conditions should be measured meticulously to reach the most advantageous and economical outcome. In this study, a particular scenario with a manoeuvring target is taken into consideration. Two of the guidance laws, namely, the pursuit guidance and the proportional navigation guidance are then implemented and compared. Lastly, the effect of the missile acceleration is examined within the proportional navigation guidance to consolidate the study.

Keywords: MISSILE GUIDANCE, PURSUIT GUIDANCE, PROPORTIONAL NAVIGATION GUIDANCE, TACTICAL MISSILE DESIGN

1. Introduction

The concept of Tactical Missile Design (TMD) is in the special interest of the Defence Industries, therefore, it should come as no surprise that the main objective is to accomplish this task with the most efficient way as possible in order to reduce the cost and development time. This design process requires a tedious analysis of various considerations, such as the scenario that is expected to be met, development and production phases of the missile, and its economical aspect to the customer.

Generally speaking, guidance laws are separated into 3 different categories. These are line-of-sight guidance (LOSG), pursuit guidance (PG), and finally proportional navigation guidance (PNG) [1]. Each of these guidance laws have trade-offs. Electronic systems of the LOS guidance missiles is relatively simple. However, LOS guidance requires commands from a control station, and therefore, susceptible to jamming. Seekers used in the pursuit guidance missiles are quite simple and durable against the noise. But their efficiency against fast moving targets is not as high as the proportional guidance missiles [2].

This study focuses on the two major guidance methods of the tactical missiles, pursuit guidance (PG) and proportional navigation guidance (PNG). In the forthcoming sections, these guidance laws are examined closely within a certain scenario, and their suitable utilizations are presented in the results and discussions section. Also, there is another section in which the impact of the acceleration of the missile is analysed in proportional navigation guidance method.

2. Prerequisites and Definition of the Scenario

Even though there are various specifications that need to be handled in designing a tactical missile, the very first step that should be considered is the threat analysis of the target. Professor Lindsley claims that experience has proven one missile cannot be designated for all types of threats without seriously compromising performance of effectiveness [3]. For this reason, PG and PNG will be performed within the same scenario, and they will be compared. For the rest of the study, subscript “M” will refer to the missile, and subscript “T” will refer to our target.

Missile that is going to be operated must meet certain functions to complete its mission. It should detect the threat, and seek it. This is achieved by the various optical instrumentations that missile includes, which will detect the target, and acquire the angular location of the target relative to a fixed system. The acquisition process provides us the radial distance between the missile and the target, r , and the angle that velocity of the target makes with the

line-of-sight of the missile, α_T . Angle ϕ which is the angle between the line-of-sight and the horizontal line and angle α_M which is the angle between the velocity of the missile and the line-of-sight are determined according to the angle α_T and to some pre-established criteria. Angles θ_T and θ_M , which are the angles between the velocity vectors and the horizontal line, can be determined from Fig. 1 and Fig. 2. For our case, the following values are selected:

- $\phi = 1.354 \text{ rad}$
- $\alpha_T = 0.750 \text{ rad}$
- $\alpha_M = 0.848 \text{ rad}$ for PNG and $\alpha_M = 0$ for PG.
- $r = 2000 \text{ meters}$
- $V_T = 300 \text{ m/s}$
- $V_M = 600 \text{ m/s}$
- Navigation ratio $k = 4$ is for PGN and $k = 1$ is for PG.

In these guidance methods, we need only one additional parameter for the sake of the simplicity of calculations and derivations. For convenience $\dot{\theta}_T$, rate of change of the angle between the target and the horizontal line, is set to value $3.2981 \times 10^{-1} \text{ rad/s}$.

3. Additional Scenario for the Effect of Missile Acceleration in PNG

Apart from the first scenario that is defined in the last section, the scenario that is going to be presented here will reinforce our previous understandings. Every value defined in the section 2 is also valid here, except the missile velocity. For the first case, the missile velocity starts with 400 m/s and it will reach to 600 m/s at the end of the propagation. The second case is the exact opposite of the first one, missile velocity decreases from 600 m/s to 400 m/s over the course. After the brief introduction of PG and PNG laws, results and discussions will take place.

4. Pursuit Guidance (PG) Law

In pursuit guidance, missile velocity vector is always directed towards the target, and the rate of turn of the missile is always equal to the rate of turn of the line-of-sight. As a result, missile constantly moves along the line-of-sight from the missile to the target whose path describes a total pursuit [4]. This is often regarded as tail-chase situation. From the Fig. 1, missile and target relationship can be visualized with the corresponding angles. Apart from the translating coordinate system, there is assumed to be an external inertial coordinate system. Leaving aside further

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comments and discussions, PG kinematics will be briefly introduced.

It is evident from the basic kinematic relationships, the velocity of the target with respect to the missile is given by [3],

$$(1) \quad \vec{V}_{T/M} = \vec{V}_T - \vec{V}_M$$

Writing absolute velocities of the target and the missile as well as the relative velocity,

$$(2) \quad \vec{V}_T = V_T \cos \alpha_T \bar{e}_r - V_T \sin \alpha_T \bar{e}_\theta$$

$$(3) \quad V_M = V_M \cos \alpha_M \bar{e}_r - V_M \sin \alpha_M \bar{e}_\theta$$

$$(4) \quad \vec{V}_{T/M} = \dot{r} \bar{e}_r + r \dot{\theta} \bar{e}_\theta$$

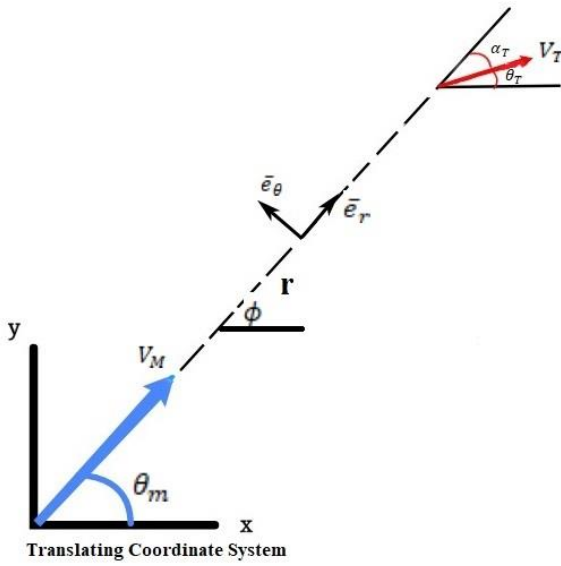


Fig. 1: Pursuit Guidance Kinematics

Inserting equations (2), (3) and (4) into the equation (1), we get our fundamental relation and the following terms [3],

$$(5) \quad \dot{r} = V_T \cos \alpha_T - V_M \cos \alpha_M$$

$$(6) \quad r \dot{\phi} = -V_T \cos \alpha_T + V_M \sin \alpha_M$$

These equations are general and can also be applied to PNG law. It can be readily seen that in PG, ϕ angle is equal to the θ_M and $\alpha_T + \theta_T$ separately. In this case, second term of the right-hand side of the equation (3) vanishes, since there is no α angle for missile. Below relations are also useful ones in the pursuit guidance law,

$$(7) \quad \theta_M = \phi \text{ and } \dot{\theta}_M = \dot{\phi}$$

Also,

$$(8) \quad \theta_M = \alpha_T + \theta_T \text{ and } \dot{\theta}_M = \dot{\alpha}_T + \dot{\theta}_T$$

Since $\dot{\alpha}_M = 0$ for PG, only time derivations of values $\dot{r}$, $\dot{\theta}_M$ and $\dot{\theta}_T$ are required. Using equations (5), (6), (7) and (8), these parameters can be achieved. With these time derivations, it is possible to find each angle at each time step, which will enable us to propagate the guidance method.

5. Proportional Navigation Guidance (PNG) Law

In Proportional Navigation Guidance method, the line-of-sight from the missile to the target does not changes direction as the distance between two objects closes [5]. In other words, if we were to connect all the positional points of the missile and the target at respective times, we would get a parallel set of line-of-sights over the course of action. Therefore, the rate of turn of the missile is proportional to the rate of turn of the line-of-sight from the missile to the target [6]. This proportionality is shown by the following relation,

$$(9) \quad \dot{\theta}_M = k \dot{\phi}$$

The multiple that is seen in the equation (9) is called navigation ratio, and it is typically between two and six. As distinct from equation (7), we have the following angular relations,

$$(10) \quad \phi = \frac{\dot{\theta}_M}{k} \text{ and } \dot{\theta}_M = \left(\frac{-k}{k-1} \right) \dot{\alpha}_M$$

It can be observed that PG can be attained by setting the ratio $k = 1$. Therefore, PNG is designed in such a way that other guidance methods can be achieved by changing this constant. Other than above equations, since equations (5) and (6) were general relations, they are also used in this method. Recalling those equations,

$$(11) \quad \dot{r} = V_T \cos \alpha_T - V_M \cos \alpha_M$$

And,

$$(12) \quad \dot{\phi} = [-V_T \cos \alpha_T + V_M \sin \alpha_M]/r$$

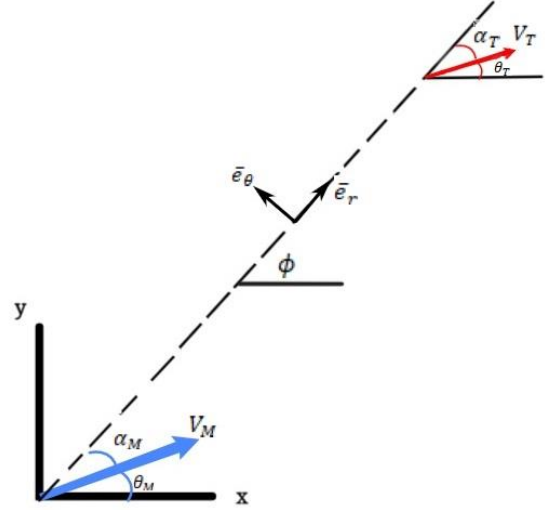


Fig. 2: Proportional Navigation Guidance Kinematics

Again, time derivations $\dot{r}$, $\dot{\phi}$, $\dot{\theta}_M$, $\dot{\theta}_T$, $\dot{\alpha}_M$ and $\dot{\alpha}_T$ are required. These parameters can be reached by utilizing equations (9), (10), (11) and (12). In the next section, these findings will be integrated into an algorithm, and that will be briefly introduced.

6. Euler's Method and Algorithm

For manoeuvring targets, the equations should be solved incrementally with time. Euler's method presents an adequate approximation for starters. Assume we have the following initial conditions, $r(0)$, $\alpha_T(0)$, $\alpha_M(0)$, $\phi(0)$, $\theta_T(0)$, and $\theta_M(0)$. Then the algorithm used is as follows [3]:

$$(13) \quad \mathbf{r}(t + \Delta t) = \mathbf{r}(t) + \dot{\mathbf{r}}(t)\Delta t$$

$$(14) \quad \alpha_M(t + \Delta t) = \alpha_M(t) + \dot{\alpha}_M(t)\Delta t$$

$$(15) \quad \phi(t + \Delta t) = \phi(t) + \dot{\phi}(t)\Delta t$$

$$(16) \quad \theta_M(t + \Delta t) = \theta_M(t) + \dot{\theta}_M(t)\Delta t$$

$$(17) \quad \theta_T(t + \Delta t) = \theta_T(t) + \dot{\theta}_T(t)\Delta t$$

Finally, we have the trajectory of the missile and the target as following:

$$(18) \quad X_M(t + \Delta t) = X_M(t) + V_M \cos \theta_M(t) \Delta t$$

$$(19) \quad Y_M(t + \Delta t) = Y_M(t) + V_M \sin \theta_M(t) \Delta t$$

$$(20) \quad X_T(t + \Delta t) = X_T(t) + V_T \cos \theta_T(t) \Delta t$$

$$(21) \quad Y_T(t + \Delta t) = Y_T(t) + V_T \sin \theta_T(t) \Delta t$$

Where the initial conditions are $X_M(0) = Y_M(0) = 0$, $X_T(0) = r_0 \cos \phi_0$, and $Y_T(0) = r_0 \sin \phi_0$. Since the algorithm have been provided with the relevant equations and the necessary information, scenario can be analysed.

7. Results and Discussions

The algorithm used in this study is implemented in the MatLab with the Euler's method, as mentioned in the preceding section. Entering the pre-determined values from the section 2, and setting the initial time and the time step to 0 and 0.1 seconds respectively will give us the following results and plots:

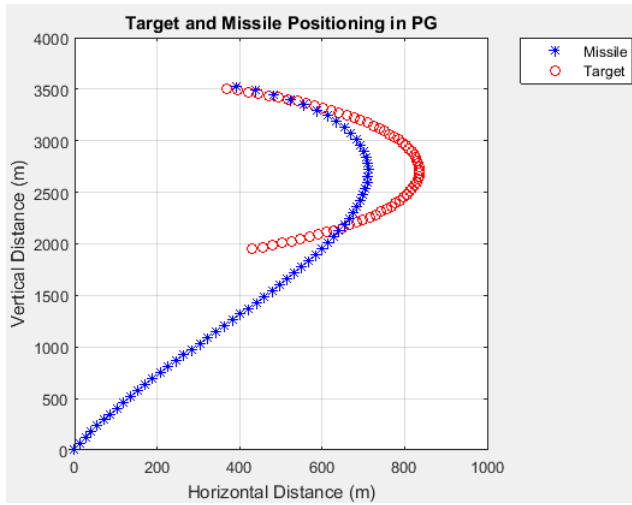


Fig. 3: Positioning of target and missile in the given scenario (PG).

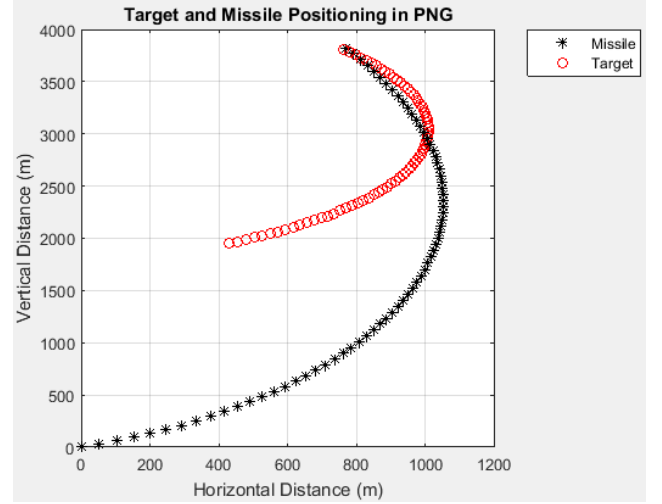


Fig. 4: Positioning of target and missile in the given scenario (PNG).

As it can be seen from the figures, even though the target movement is same, missiles have different attitudes in PG and PNG. Pursuit guidance paths are highly curved near the end of the propagation, therefore, missiles need to attain much higher accelerations. However, acceleration may reach to a point which a certain missile may not afford that specific manoeuvre. For example in Fig. 3, the maximum acceleration of the missile is calculated as $148.1 g$, and this value may not be supported by the missile structure and electronics. For this reason, the most common application of the pursuit guidance is against slow moving targets. Also, since the target position is in special interest in PG, position determining depends on looking and pointing, therefore, avionics and control is simple relative to PNG [3]. This is called target heading, and it can be considered as inexpensive and light.

On the other hand, in Fig. 4, missile propagates on a less curved path, and does not tail-chase the target. Instead, it anticipates the targets future position and tries to cut its way at all times. Maximum acceleration of the missile is calculated to be $30.03 g$ which is also in the reasonable range. The lead angle of the missile in this procedure is regulated by the navigation ratio. Moreover, since the line-of-sight changes throughout the course of action, it has to be sensed by the missile avionics. Thus, avionics required in PNG is more complex and expensive than other guidance methods.

The following figures, namely Fig. 5 and Fig. 6, present the results for the scenario that is defined in the section 3. It is seen that there is a slight difference in the terminal phase (last phase) of both cases. It is also found that the maximum magnitude of the acceleration attained in accelerated case is $10.2 g$, while the maximum magnitude of the deceleration case is $30.1 g$.

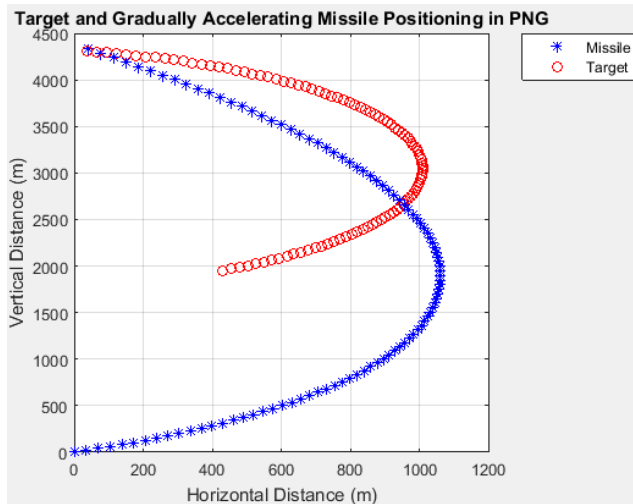


Fig. 5: Accelerated missile scenario in PNG.

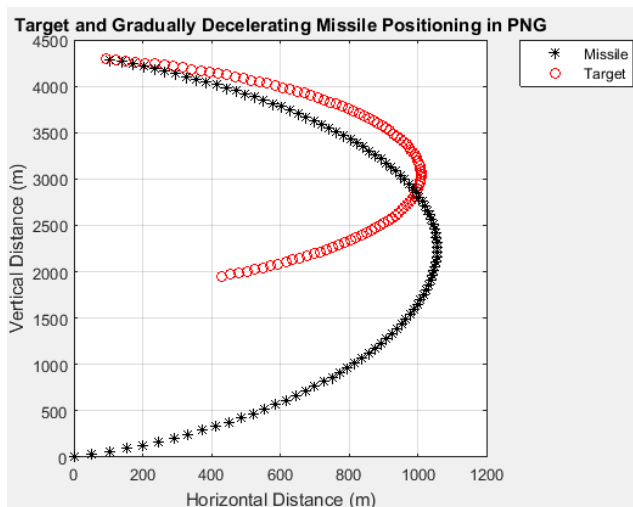


Fig. 6: Decelerated missile scenario in PNG.

As it is obvious from the figures, there is no significant visual distinction between accelerated and decelerated cases. However, this is due to small amounts of acceleration; as the acceleration increases in magnitude, the target is hit much earlier in the accelerated case with respect to the decelerated case. This is also illustrated in the Fig. 7.

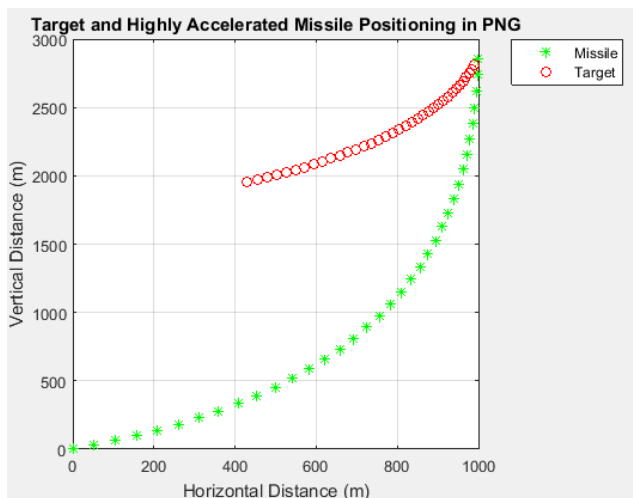


Fig. 7: Highly accelerated missile scenario in PNG.

In the case of the highly accelerated missile, magnitude of its maximum acceleration is $35.1 g$. These specifications purely dependent on the scenario and on the mission that is meant to be met. Last, but not least, these attained maximum acceleration values can be deceptive; bear in mind that that this value is the resultant magnitude of the radial and the angular components of acceleration.

8. Summary and Conclusion

In this study, PG and PNG laws are compared for the constant speed missile first, then variable speed missile is examined within the PNG method. Besides from comparisons between PG and PNG in the previous section, missile acceleration affects arrival time and miss time. It can be observed that highly accelerated missile reaches the target faster than any of the situation that are mentioned before. For gradually accelerating and gradually decelerating cases, there is no obvious distinction, there is only small change in the missile behaviour.

In the light of above findings, it can be stated that PG performs poorly against accelerated targets, while PNG is more decisive. The situation is not different with target heading accuracy. However, complex avionics of the PNG generates much more noise relative to PG. Even though these methods are examined and compared in terms of superiority in this study, there are way better guidance methods utilizing the newest technologies. However, examination of PG and PNG is vital in terms of understanding the basics and the concept of tactical missile guidance.

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IMPACT OF TECHNICAL VALIDITY MOTORCYCLE FOR ROAD SAFETY IN THE REPUBLIC OF CROATIA

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Abstract: The road traffic safety factor is divided into three basic groups: human, vehicle, road (infrastructure). Technically defective, poorly maintained and technologically obsolete vehicles endanger road safety. The number of technically defective vehicles that are involved in traffic accidents, when checks are carried out by officers of traffic police, is 0.2%. Considering that 21.31% of vehicles are found to be defective by periodical technical inspections of vehicles (PTI), it is expected that the number of technically defective vehicles in daily traffic is considerably higher. By analyzing the data collected by PTI and comparing them with the data obtained during the conducted research "Inspection of the technical safety of vehicles involved in road traffic accidents with fatalities" the real state of the technical condition and safety of vehicles on the roads in the Republic of Croatia is presented here. Two-wheel vehicles (mopeds and motorcycles) represent a particularly risky group.

Keywords: SAFETY, ROAD TRAFFIC, INSPECTION, MOTORCYCLE

1. Introduction

Reducing the number of traffic accidents can only be achieved through active involvement of all traffic participants, optimizing the relationship between safety factors human, vehicle, road (infrastructure). Action measures to better road safety include legislation, education, information, maintenance, modernization and infrastructure construction, increasing passive and active safety, the technical safety of vehicles and the reaction speed of the emergency services. Technically defective, poorly maintained and technologically obsolete vehicles endanger road safety. The Center for vehicles of Croatia (CVH) organizes and conducts periodical technical inspection of vehicles (PTI) in the Republic of Croatia. With the aim of presenting the actual state of technical validity of vehicles on the roads of the Republic of Croatia, the CVH with the Ministry of the Interior (MUP), the Croatian Automobile Club (HAK), the Faculty of Transport and Traffic Sciences (FPZ), the Faculty of Mechanical Engineering and Naval Architecture (FSB) has initiated the research project "Inspection of the technical safety of vehicles involved in road traffic accidents with fatalities"[1]. The aim of the research project is to show the impact and frequency of technical malfunctions in traffic accidents with fatalities in the Republic of Croatia, and propose measures related to the technical validity of the vehicles to further increase traffic safety based on the results of the research. During drivers' everyday use of the vehicle, malfunctions can easily be recognized and detected on critical parts of the vehicles such as tires, suspension, braking system, steering mechanism and light signaling equipment. Although these malfunctions are relatively easy to remove in the average automobile workshop without special tools, the owners are not prone to correct them in the timely manner. Instead, the most common defects are removed just before PTI and some of them only after being identified by the PTI. Therefore, the driver's responsibility is a big gray zone when it comes to the lack of maintenance.

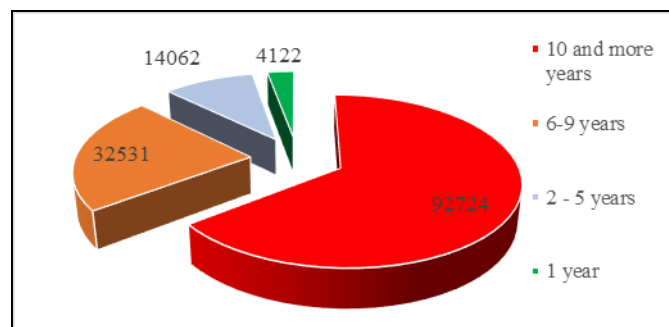


Fig. 1 Mopeds and motorcycles in the Republic Croatia

2. Periodical technical inspections of vehicles

All vehicles involved in road traffic must be without technical malfunction and it must be ensured that their use has minimal impact on the environment. In Croatia, all motor vehicles and trailer based on the Law on Road Traffic Safety are subject to PTI. The period required to conduct the review, the content and scope of the review, as well as the requirements for qualified staff and equipment, are prescribed [2]. The purpose of the vehicle's technical inspection is to detect vehicle defects that could affect the safety of the vehicle and passengers as well as other traffic participants.

2.1. Results of PTI

Vehicles, all their parts and equipment must be completely in working order, but from the safety point of view some circuits are more important than others because they directly affect traffic safety. In 2017, 2.065.038 PTI were carried out [3]. The average percentage of vehicles with malfunctions was 21.31% and the average age of the vehicles was 13.99 years (Fig. 1). Considering the high average age of the vehicle and the fact that the majority of vehicle owners prepare and remove malfunction on the vehicle immediately before the technical inspection, it is realistic to expect a significantly higher percentage of defective vehicles in daily traffic, therefore we consider these data to be the starting point of the research.

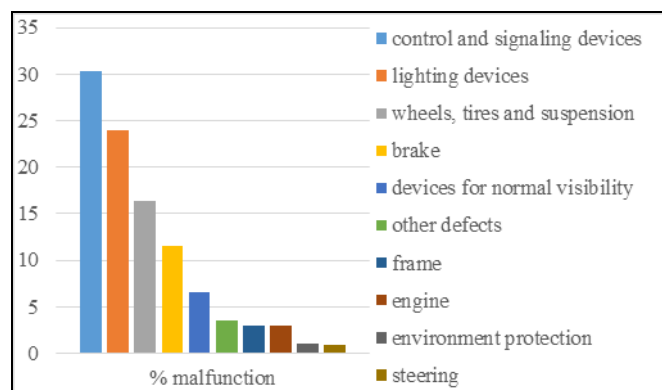


Fig. 2 Distribution of the most common malfunctions by mopeds and motorcycles

There are 143.439 two-wheeled vehicles: 79.873 mopeds, and 63.566 motorcycle. Mopeds and motorcycles in total represent 6.94% of road traffic vehicles and 8.16% of all defective vehicles the highest percentage of deficiencies on PTI of mopeds and motorcycles refer to control and signaling devices 30.28%, lighting devices 23.99% wheels, tires and suspension 16.30%, brakes

11.52%, devices for normal visibility 6.51%, other defects are represented by 3.49%, frame 3.00%, engine 2.94%, environment protection 1.05% and steering of 0.91% (Fig. 2). The age of the vehicle and its usage over time has a significant impact on vehicle malfunction. The average age of mopeds and motorcycles in the Republic of Croatia is 12.3 years, and the average annual travel time is approx. 1.400 km for mopeds and approx. 2.800 km for motorcycles.

3. Research, "Inspection of the technical safety of vehicles involved in road traffic accidents with fatalities"

According to statistical data from the Republic of Croatia, 94.8% of traffic accidents are caused by the human factor, while only 0.2% of accidents are caused by technical malfunctions [4]. In the Republic of Croatia, a technical inspection of the vehicle is not carried out after a car accident, unless there is doubt in the technical malfunction of the vehicle or the competent state authority is requiring the technical inspection. Given the large number of traffic accidents in Croatia, the research project targets groups of vehicles that participated in traffic accidents with fatalities. The technical inspection of the vehicle's technical validity after the car accident is significantly different from the PTI of the vehicle since the vehicles are usually significantly damaged and therefore disassembly, assembly and, if necessary put into operation. It gets carried out as soon as possible after an accident in the field or a workshop with the tool and equipment of an automobile workshop. The results of the inspection are noted on a specially prepared vehicle inspection form, and all collected data and photos are archived in a special application. The aim of the research project is to show the impact and frequency of technical malfunctions in motor accidents with fatalities in the Republic of Croatia, and suggest measures that impact technical vehicle correctness to increase traffic safety based on the results.

3.1. Research results

The data was collected by a team of experts who conducted a vehicle inspection after a traffic accident with fatalities. After reviewing the vehicle, based on the collected data, the members of the expert team gave their opinion on the technical condition of the vehicle and its parts and equipment - classified into three categories (Fig. 3):

- technically adequate,
- technically inadequate,
- it is not possible to determine the condition before the accident.

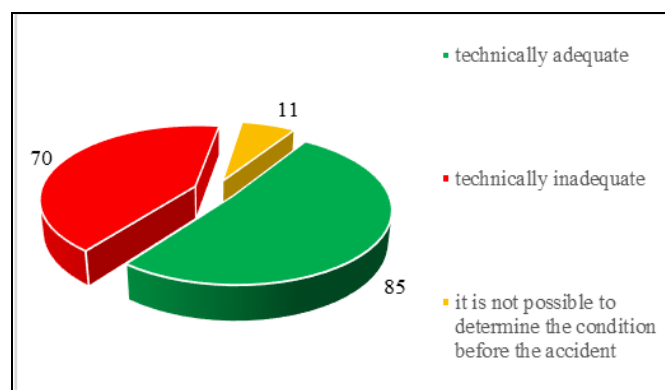


Fig. 3 Structure of vehicles involved in traffic accidents with fatalities according to technical condition.

During the research, 166 vehicles were involved in traffic accidents with fatalities and according to the procedure described, 85 vehicles or 51.20% were technically correct, while 70 vehicles of the vehicle inspected or 42.17% were shown to be technically

inadequate, which is twice as high as on a PTI of the vehicle. The average age of these vehicles was approximately the same 14.54 years, which is in the range of expected values due to the average age of vehicles in the Republic of Croatia and the fact that most vehicle owners service the vehicle before the PTI. For 11 vehicles or 6.63% it was not possible to determine the condition before the accident.

A total of 23 mopeds and motorcycles were inspected, 13 or 56.52% of which were defective and one or more malfunctions were identified on them. By comparing the proportion of mopeds and motorcycles with other vehicle categories and taking into account the extremely small average annual travel distance, these vehicles are a particularly risky group in terms of technically defectives. Although technical malfunctions can often not be identified as a direct cause of a traffic accident, some of the malfunctions are extremely serious and dangerous, the so-called "dangerous mistake". The highest percentage refers to wheels, tires and suspension, 38.46%, brakes 30.77%, engine 30.77%, frame 23.08%, lighting devices 7.69% (Fig. 4). If we compare the data on PTI of mopeds and motorcycles with data determined by research, it is shown that statistical data correlates with the data obtained during the research although there are variations in the order of frequency.

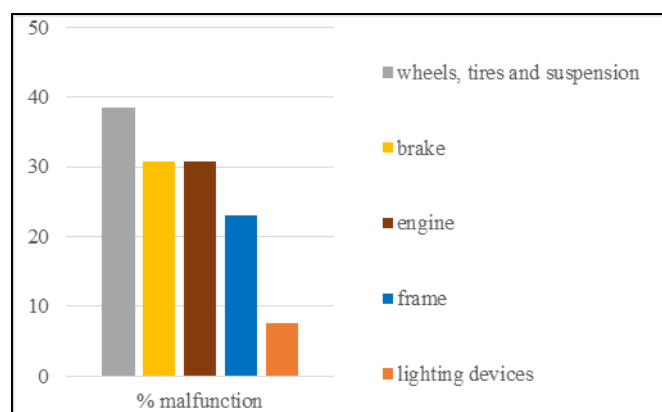


Fig. 4 Overview of "dangerous mistake" on mopeds and motorcycles

4. Conclusion

Technically defective, unmaintained and technologically outdated vehicles compromise road traffic safety. The numbers of the technical malfunctioning of vehicles involved in traffic accidents is 0.2%, when checked by traffic police officers and it is published in the bulletin of the Ministry of the Interior. Research of traffic accidents with fatalities for mopeds and motorcycles, which account for only 6.94% of road traffic vehicles, indicate that in 14.3% of traffic accidents technical failure is a possible cause of traffic accidents. The differences in the values determined from inspection carried out by traffic police officers can primarily be attributed to the different methodology of data collection and analysis, the way of keeping statistics, the conduct of the evidence, the determination of the causes of the accident, the record of the cause of the accident and due to the fact that police officers organize extraordinary technical examinations only if they doubt that there are technical defects of the vehicles involved in a car accident. The high percentage of established malfunctions through the conducted research confirms the experience and expertise of team members as well as the advantages of individual analysis of the possible technical causes of the accident. Technical malfunctions are certainly not the main cause of accidents involving mopeds and motorcycles. Much more accidents happen due to human error, however, accidents due to technical malfunctions can be avoided (or reduce the consequences) if these malfunctions were detected on time and fixed or if the vehicle is maintained in a technically correct condition. Through the research we established that mopeds and motorcycles are technically defective, which alone

with their short annual period of use and a small distance travelled makes them exceptionally risky, also enhanced by their performance and unprotected drivers. Motorcycle aging has a very negative impact, and it is very likely that a malfunctioning or insufficiently maintained motorcycle will be the cause of a traffic accident or is more likely to affect an adverse event.

The results of the research, data on the causes of the accident, the technical condition of the vehicle and the methodology of vehicle inspection should be directed towards reducing the number of accidents in road traffic. It is necessary to carry out promotional campaigns and educational actions with the aim of informing the public about the importance of technical correctness of vehicles, maintenance and control and the fatal consequences of the use of technically defective vehicles. The formation of a multidisciplinary team of professionals who will use their skills and with special equipment will be able to reconstruct the course of traffic accidents, analyze the technical validity of the vehicle, the driver's behavior when driving and the impact of the infrastructure is necessary, propose measures to increase traffic safety. It is recommended to increase the number of technical inspections of the motorcycle in everyday traffic as well as to carry out technical roadside inspections, and raise attention to critical parts and motorcycle assemblies during PTI of the vehicle. Pointing to the fact that increased age and distance traveled increase the possibility of using a defective vehicle, measures to stimulate the purchase of new vehicles should be proposed.

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APPLICATION OF GEOGRAPHICAL INFORMATION SYSTEMS TO EVALUATION A CONCENTRATION OF CHLORINE RELEASED INTO AN ATMOSPHERE IN THE CASE OF ROAD ACCIDENT

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Abstract: Modelling propagation of hazardous substances released in road accidents is important issue from the point of view of safety in road transport. The paper presents use of the Geographic Information Systems to analyse the impact of the emissions of hazardous compounds in the built-up area. In the paper dispersion of pollutants released in a road accident, involving a chlorine tanker truck, followed by chlorine spillage has been analysed. It is assumed that the accident took place in a mountainous area on a bypass within a built-up area. Concentrations of pollutant have been calculated in the own program. The calculation of field of wind speed was taking into account the terrain elevation and type of land cover. The package Idrisi Taiga has been applied in the pre-processing stage. It was used to generate a site map with buildings and aerodynamic roughness map. Meteorological conditions were also taken into account: wind speed and direction, temperature, atmospheric pressure and atmospheric stability class. The computer program consist two basic modules: diagnostic model of air velocity field and Lagrangian model of particles, being the original implementation of the Lagrange model of particles. In both models, some elements of mathematical modelling were applied. The models have been successfully validated and verified. The results of the calculations of concentrations of chlorine have been analysed in the Geographic Information System. The following analyses have been made, among others: designation of hazardous zones AEGL 1-3, determination spatial size of built-up areas within the zone, analysis of changes in pollution concentrations over time. The proposed analyses allows to determine areas exposed to deadly and highly dangerous concentration of chlorine.

Keywords: COMPUTER MODELLING, ROAD SAFETY, ROAD TRANSPORT, POLLUTION DISPERSION, HAZARD MATERIALS, GIS ANALYSIS

1. Introduction

Modelling the propagation of hazardous substances released as a result of a road accident is an important element in the assessment of hazards resulting from the use of transport means to transport chemical substances. Determining the probable effects of a tanker collision that results in leakage into the air is possible due to the use of computer programs such as ALOCHA or HPAC, but they do not take into account many elements, such as the complexity of the topography of the terrain. These elements can be taken into account thanks to the use of proprietary computer models and programs.

Computer simulations for the case analyzed in this paper regarding a sudden road accident with the participation of a chlorine tanker were carried out in proprietary programs based on the diagnostic model of the air velocity field and the Lagrange model of particles. In both models, elements of mathematical modelling were applied. These models were validated and verified (Brzozowska, 2013; Brzozowska, 2014a).

An analysis of the spread of pollutants as a result of a road accident involving a tank carrying chlorine is presented, accompanied by a leak of substance into the air. The occurrence was simulated in the city of Bielsko-Biala (Poland), on the bypass road in the built-up area.

At the stage of pre- and post-processing, the GIS Idrisi Andes Spatial Information System was used.

2. Modelling the effects of releases of hazardous substances in transport

2.1. Serious accidents in road transport

According to data provided on the European Commission's Eurostat websites, in the years 2012-2016, in the European Union, road transport carried from 74 billion t km to 84 billion t km of hazardous goods. Also in Poland, the transport of hazardous goods from year to year is growing (according to the same commission) and in 2012 it amounted to 6 801, in 2015 already 9 174 million t km, and in 2016 8 444 million t km, which was ca. 3% of the total amount of goods transported by road (Transport, 2016).

The safety of road transport is regulated, among others, by the provisions of the European Agreement for the International Road Transport of Dangerous Goods (ADR). It is a widely used standard, subject to constant amendments in the forum of the United Nations Economic Commission for Europe. In Poland, there is also the Act of 19 August 2011 on the transport of dangerous goods (Journal of Laws 2011 No. 227 item 1367), which defines the rules for the transport of dangerous goods.

According to the analyzes carried out by the Supreme Audit Office (NIK, 2012), irregularities were detected in about 5% of the vehicles inspected, most of them related to incorrect security in the event of a fire.

The subject of the problem of transport of dangerous substances is taken by many authors. At work (Oggero et al., 2006), an analysis of 1,932 cases has been made, which occurred during road and rail transport of hazardous substances from the beginning of the 20th century to July 2004 in Great Britain. The obtained results indicate an increase in the frequency of major accidents (incidents) over the time. Over half of the accidents happened on roads (63%). The most common accidents were related to the releases - 78%, then with fires - 28%, explosions - 14% and gas clouds - 6%. The causes of accidents were analyzed, the type of substances and the consequences for the population (number of people killed, injured or evacuated).

In the United States (Erkut et al., 2007) the most cases concerned flammable materials - over 42%, caustic materials - 37.5%, poisonous - more than 5%, oxidants - 3% and mixed - almost 4%. Other accidents - more than 8% related to other hazardous substances. About 40% of accidents involving hazardous materials were caused by human error and also as a result of road accidents, and almost 20% were related to the failure of containers.

Welles et al. (2004), based on research carried out in New York, states that: 21% of accidents related to hazardous substances occur in relation to transport, 39% due to faulty equipment and 33% due to human error.

The assessment of the effects of this type of events is a considerable task and requires the use of appropriate tools.

2.2. Modelling the effects of major accidents in road transport

The impact of accidental releases of toxic chemicals can be minimized by providing accurate information and organizing the work of the team to prevent the effects of major accidents. This is possible thanks to the use of programs and computer systems that allow to estimate the effects in real time. They are a key tool to support decision-makers in the planning of pre-trial and rescue proceedings in case of an accident (Alhajraf et al., 2005, Quaranta et al., 2002, Zhao et al., 2012). An example of such a system may be ARAC (Atmospheric Release and Advisory Capability) developed by Lawrence Livermore National Laboratory (LLNL) (Ermak et al., 2002). In these systems, one of the necessary modules is the dispersion module. Spatial information systems are also used, among others to estimate the number of people in the range of danger (Chakraborty and Armstrong, 1995, Fisher et al., 2006).

A variety of computer programs are used to model the effects of releases of hazardous substances. In the programs used in Poland by the State Fire Service to assess the toxic zones of vapours hazardous to health and life arising during chemical spills, the direction and speed of the wind, the class of atmosphere stability and air temperature are usually taken into account. The most frequently used programs include: ALOHA (Areal Locations of Hazardous Atmospheres), a program for estimating hazardous areas in the event of emergency release of hazardous substances (NOAA, 2013); ALOFT-FT (A Large Outdoor Fire Plume Trajectory Model - Flat Terrain - McGrattan (2003)); FDS (Fire Dynamics Simulator - McGrattan et al. (2007)); CFAST (Consolidated Model of Fire Growth and Smoke Transport - Peacock et al. (2013)). The ALOHA program is mainly used because of its ease of use. The results are presented in the form of graphic zones whose boundaries can be defined individually. In the program, indirect construction can also be taken into account by selecting one of three possible types of aerodynamic roughness of the ground.

In this work, we used our own computer program based on independently operating models: air velocity field and dispersion of pollutants. The first of them belongs to the group of diagnostic models, the second is the original implementation of the Lagrange model of particles. The flow chart is shown in Fig.1.

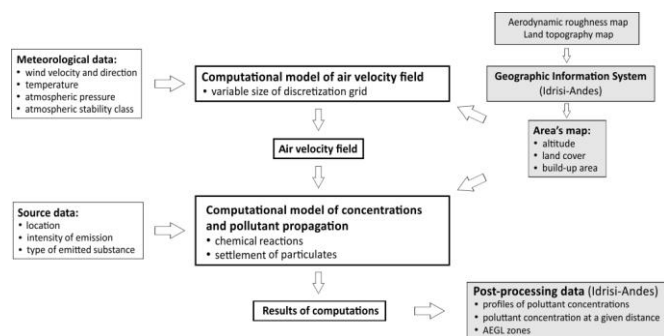


Fig.2. Stages of proceedings in the custom program

The description of mathematical models is presented in Brzozowska L., (2013) and Brzozowska L., (2014a), and their implementation and application to the simulation of the effects of dangerous substances, among others, in: Brzozowska L., (2014b) and Brzozowska L. (2016).

3. Analysis of the effects of the sudden release of chlorine resulting from a road incident

This chapter presents the use of the Spatial Information System to analyze the effects of the sudden release of a dangerous substance resulting from a road accident involving a tanker carrying chlorine (Brzozowska L., 2016). Analysis and visualization of results was carried out in the Idrisi Andes program.

3.1. Chlorine as a hazardous substance

On the one hand, chlorine, used for the production of industrial and consumer products, helps improve the quality of everyday life (Clugg, 2012, Dandrieux et al., 2006), on the other is also very toxic and considered one of the most dangerous materials from the hazardous materials group. Classified as Toxic Inhalation Hazard (TIH) and Poison Inhalation Hazard (PIH). Gaseous chlorine becomes particularly dangerous when released into the air. The risk of exposure depends on how close the source of release is to a given person. Chlorine is easily dispersed in atmospheric air and can therefore be a threat to a large population. Ultimately, the consequences of the release depend on the intensity of the emission, the location of the source, the shape and type of surrounding terrain and meteorological conditions. Any unintentional release that is not associated with an accident is called 'Non-Accident Releases' (NARs) (Clugg, 2012).

One of the major disasters associated with the transport of chlorine was the train accident on January 6, 2005, in Graniteville, South Carolina, which resulted in the car bursting and the release of 54 tons of chlorine (Railroad Accident Report, 2005). Over 5,000 people were evacuated in a sparsely populated area; over 500 people required treatment; nine people died. Both this accident and others caused that urban planners and emergency, transport and chemical industries had to deal with the issue of the sudden release of chlorine. In addition, the transport of dangerous substances may become the target of terrorist attacks in the urban area (Bauer, 2013, Buckley et al., 2012).

The simulations of spreading in several prognostic models carried out by Hanna et al. (2008) suggest that lethal concentration from large chlorine releases (50+ tons) will be maintained in a toxic cloud more than 10 km long in the wind.

3.2. The analyzed case

In the calculations, it was assumed that the accident occurred on the Bielsko-Biala bypass, on the S69 road (Fig. 2). There is a sharp turn here. As Fabiano et al. (2005) points out, the areas where traffic accidents most frequently occur are curves as well as tunnels, uphill slopes and high downhill slopes.

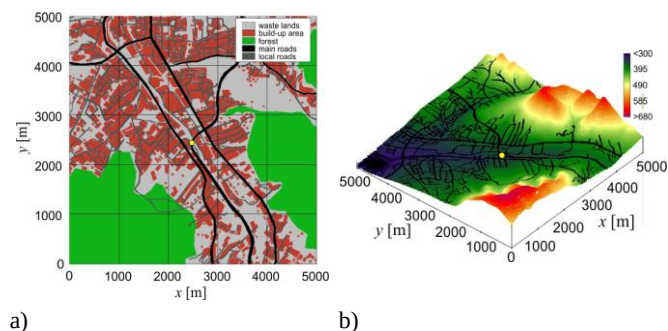


Fig.2. Modelling area with buildings - a) and terrain - b) the place of the collision and the route of the bypass road were marked

As a result of the collision of a tanker carrying 20 tons of chlorine, chlorine leaked into the air in the amount of 10 tons. It was assumed that the leak had a Gaussian curve, and most of the substance was extracted within the first hour of simulation (70%), the duration of the simulation was set to two hours. The maximum leakage is 4500 g/s.

The emission took place at a height of 1.5 m above the ground surface - roadway, in a place with coordinates $x^{(1)} = 2500$ m and $x^{(2)} = 2250$ m (this place is marked in figure 2), in built-up area. The wind direction at the time of chlorine leakage is the eastern direction, the wind velocity taken as input to the diagnostic model (when calculating the initial air velocity field) is $u = 2$ m/s. Atmospheric condition, air temperature 20°C. Two wind directions were considered: Case 1: east - E ($u^{(1)} = -2$ m/s, $u^{(2)} = 0$ m/s) and Case 2: south-east - SE ($u^{(1)} = -1.5$ m/s, $u^{(2)} = 1.5$ m/s).

3.3. Assessment of the effects of chlorine emission as a result of an sudden road accident

A series of analyzes of the simulation results obtained in the custom computer program were carried out. The analyzes were performed in the spatial information system Idrisi Andes.

Chlorine threshold values compliant with the 30-minute chlorine exposure standards - AEGL, as well as the value of 0.1 mg/m^3 , as the maximum permissible 30-minute concentration specified in Polish law, were adopted for the analysis. The limit values for AEGL are: AEGL-3 – 81 mg/m^3 , AEGL-2 – 8.1 mg/m^3 , AEGL-1 – 1.5 mg/m^3 .

Figure 3 shows the simulation area where the concentrations reached values above 0.1 mg/m^3 . Profiles selected for further analysis were also marked. In contrast, Figure 4 presents the results of modelling with marked built-up areas under the influence of AEGL-1 ... 3 concentrations.

Both wind directions were considered.

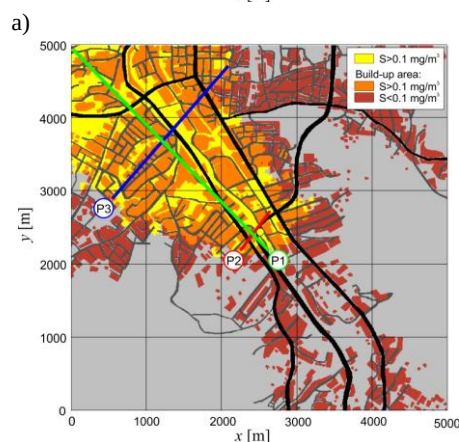
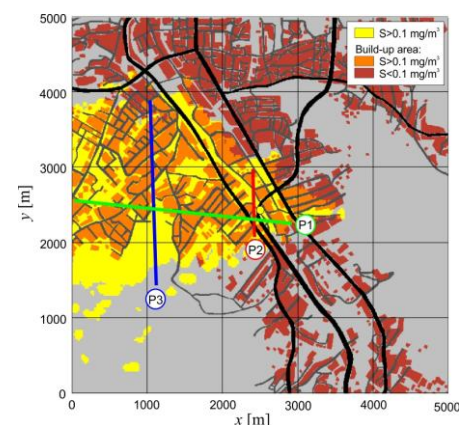
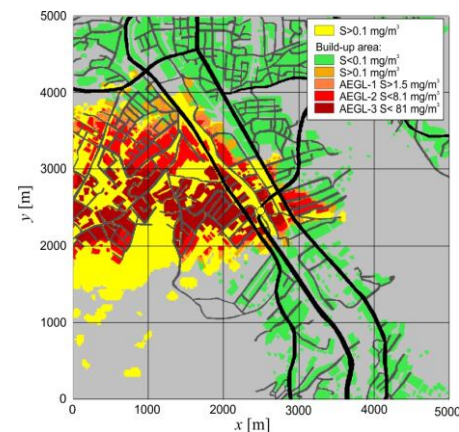
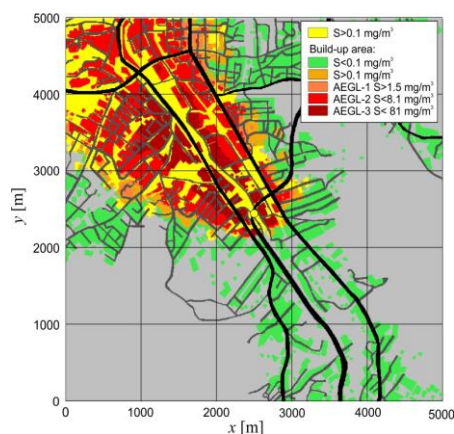


Fig.3. The modelled area under the influence of the pollution cloud and the analyzed profiles for two wind directions: a) case 1, b) case 2.



a)



b)

Fig.4. The modelled area under the influence of pollutant concentrations with different values, for two wind directions: a) case 1, b) case 2.

Table 1 shows the percentage of the risk of sudden release of chlorine as a result of a traffic accident.

Table 1. The area under the influence of pollutant concentrations above the threshold values for both wind directions

AEGL zones	Build-up area [%]	
	Case 1	Case 2
AEGL-1	2.8	3.2
AEGL-2	11.9	23.2
AEGL-3	15	10.1

The following figures (Fig. 5) present simulation results for selected profiles. The profile of building and pollution concentrations is presented.

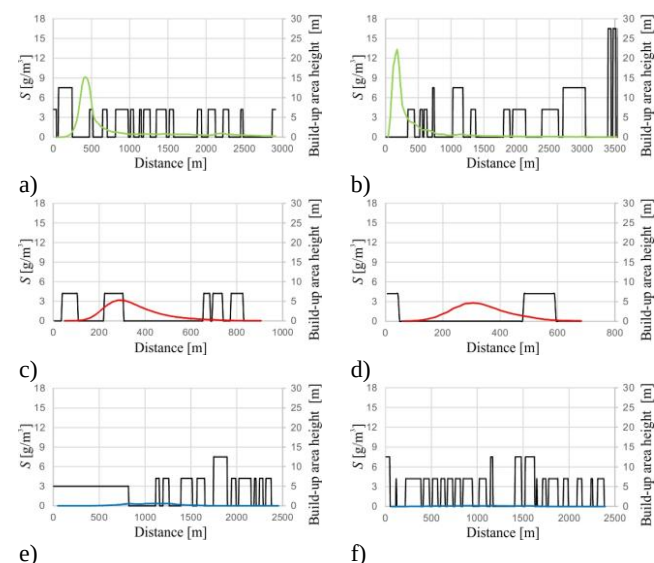


Fig.5. Elevation and pollution profiles: a) P1, case 1, b) P1, case 2, c) P2, case 1, d) P2, case 2, e) P3, case 1, f) P3, case 2.

Figure 6 shows the values of average concentrations in the building area depending on the distance from the emission source.

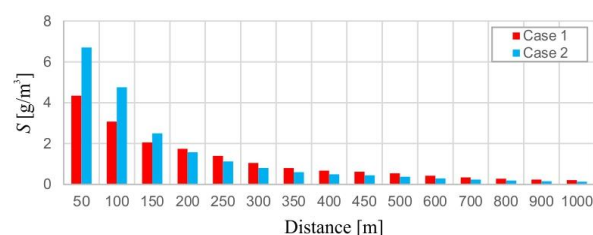


Fig.6. Pollution concentrations at a distance from the source for both analyzed cases.

4. Summary

Import of simulation results into the spatial information system enables to perform a series of spatial analyzes of calculated distribution of pollution concentration in it. The GIS software has built-in modules that are used during the development of charts and maps presenting information relevant to the surface of the earth. The maps developed as part of the work illustrate areas exposed by the occurrence of above-normative concentration levels (endangered areas). They can be used for taking action during the crisis (unsealing of the tank in which the toxic substance is transported).

After the computer simulation, it was found that the chlorine pollution cloud, in which the concentration of pollution exceeds 0.1 mg/m^3 , covers 24.3% and 24.9% of the entire area. Built-up areas under the influence of this concentration constitute 33.8% and 42% of the building area, respectively for case 1 and case 2.

Detailed analysis of the concentration of contamination in the streak axis (profile 1) and across the streak (profiles: 2 and 3) shown in Figure 5 indicates that the highest values of the pollutant are emitted in the immediate vicinity of the emission source. The maximum value of pollutant concentration for profile P1 in both cases exceeds 9 g/m^3 . Also, large concentration values are observed in the graphs for P2 profiles ($S > 3 \text{ g/m}^3$). Only at a considerable distance from the source (P3 profiles) the concentration of contamination is clearly smaller. The maximum concentration then does not exceed 360 mg/m^3 . But it is more than 4 times the threshold value of AEGL-3.

In both analyzed cases, about 3% of the development area is within the pollution concentration range in the AEGL-1 zone. Built-up areas with a concentration threatening the health of living organisms (AEGL-3) constitute 15% (case 1) and 10.1% (case 2) of the whole area of buildings. Rescue operations (zone AEGL-2) can be taken at 11.9% and 23.2% of the area.

The analysis of average values of concentration of pollution in the area of buildings at a given distance from the source of emission testifies to the occurrence of high chlorine concentrations over 1 km (207 mg/m^3 - case 1; 134 mg/m^3 - case 2) from the place of unsealing the tank. Therefore, from the point of view of health care for residents, using the discussed software one should develop a map of the threatened areas, draw up maps of evacuation plans and indicate places of road blockade.

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EXPRESSION OF RISK THROUGH TARIFF POLICY IN RAIL PASSENGER TRANSPORT

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Abstract: Risk analysis is a process with a detailed identification of risks, determine their range and examines the interaction of these risks. Each process or human activity are influenced by many risks. As well as in rail transport there are many risks which hare accrue from the operation. Risk is defined as the chance that something will happen what will affect the goals and is measuring by results or estimate. We can also risk defined as the product of the likelihood of an adverse event (phenomenon) and consequences (outcomes). On one side is the risk connected with the hope of achieving a good financial results, but on the other side with the danger of business failure that brings losses. The aim of this paper is the proposal of a tariff taking into account the risk from unoccupied capacity of passenger trains. Pricing of selected risk we will eliminate this adverse event.

Keywords: RAILWAY PASSENGER TRANSPORT, RISK, TARIFF POLICY, COSTS

1. Introduction

The term "risk" has many meanings, and is differently defined in the scientific literature, legal norms and various dictionaries. The meaning of this term depends on the field of activity, for which it is defined, on the purpose of the risk definition, and on its subsequent use.

Rail transport as a whole is affected by a number of risks that may arise in different parts of the process and may diversely affect various entities involved in the transport. Risk is defined as an opportunity that it will become something that has an impact on the goals, and is measured by the consequences or an estimate of the probability [1 and 2].

2. Risk from Unoccupied Capacity of a Selected Passenger Train

Risk from unoccupied capacity is one of many risks in the rail passenger transport which may cause a reduction in profit to the carrier, even the incomplete payment of its costs and subsequent loss. This is the risk, when the carrier shares the loss in the operation of passenger rail transport arising from circumstances that can occur before the transport or during the process of transport and that are not included in the final price of transport [3 and 2].

3. Cost Analysis for a Selected Train

Knowing the costs of operations and processes is an essential tool of economic management in the company. In the market environment it is necessary to monitor the costs in several ways. Calculation of own costs in the company should be adapted to the opportunity to analyse and plan the costs for individual activities and processes. Currently, the cost calculations are assigned to the controlling system and are known as cost controlling. It is a broader term which includes not only the monitoring of the costs actually incurred in the activities and processes, but also their planning and control, i.e. we can talk about the cost management in the company [4 and 5].

Total own costs for transport by rail can be calculated according to the formulas that take into account indicators of transport work and relevant cost rates. The basic formula may have the form [4 and 6]:

$$C_t^{total} = C_{\pi} + C_i + C_{ic} + C_{lc} + C_{ri} + C_e + C_i$$

where:

C_{total} - Total costs of a train

C_w - Costs of carriages

C_l - Costs of locomotives

C_{lc} - Costs of the train crew

C_{lc} - Costs of the locomotive crew

C_{ri} - Costs of the rail infrastructure

C_e - Costs of energy

C_i - Indirect costs

In the introduction of the analysis of risk from unoccupied capacity of the selected passenger train its identification is important, i.e. detection of all possible effects that cause this risk. For the proper identification of the risk the detailed analysis of the costs which enter this process is significant. The risk identification and analysis of the costs are applied to a model example for the session Bratislava - Trenčín - Žilina - Poprad - Košice with the configuration of the train: locomotive 131 + Ampeer + WRRmeer + 6x Bmpeer [7,8 and 9]. All needed parameters of the model train are in Table 1.

Table 1 Basic Parameters of the Model Passenger Train

Configuration of the train on the session BA - KE	Weight [t]	Places for seating
1x Ampeer	49	54
1x WRRmeer	46	0
6x Bmpeer	44	76
Locomotive 363	87	
Total gross weight	446	510
Distance [km]	445 km	
Infrastructure fee *	€461.47	

* calculated with a calculator ZSR [10 and 11]

Division of costs is often modified by a calculation formula. The transport company may use more these formulas (e.g. for individual organisational units or for individual business areas). An essential aspect of the division of costs in the calculation formula is their division into direct and indirect costs [12 and 13]. Cost analysis for the model train is shown in Table 2.

Table 2 Calculation of the Costs for the Model Train

Σ carriage kilometres : 3,560	Costs of the carriages : €2,848
Σ train kilometres : 445	Costs of the locomotive : €289.25
Σ hourly rates for locomotive crew : 6	Costs of the locomotive crew: €84
Σ hourly rates for train crew : 6	Costs of the train crew : €330
Σ gross tonnage kilometres (GTKM) : 105,198	Costs of the energy : €287.19
Specific consumption (kWh/1,000 GTKM) : 18.2	Indirect costs : €1,842.82
Travel time (hour) : 5	Total costs of the train : €6,142.73

The total costs of the model train from Bratislava via Zilina to Kosice are €6,142.73.

4. The Proposal of the Tariff Taking into Account the Diverse Occupancy of the Train

The proposal of an optimal tariff (100% occupancy of seats) can be obtained based on the proportion of the total costs and total number of seats when we get the costs of one seat in the whole session. After rounding up the result to an integer, which constitutes a reasonable profit, and from the resulting price for transport over the entire session we will derive prices for transport in individual sections. This will be the basis for creating the relational tariff. The price for individual sections is formed with regards to the distance, but like with the entire session, the results are rounded up, and that should mean a reasonable profit for the carrier. Another form of profit growth is to propose a surcharge to the ticket in the first class, which would mean €4 / one seat.

Revenues are calculated through multiplying the number of occupied seats in the second class with the price for the transport throughout the whole session, plus revenues from the first class (the same way). At the formation of a tariff policy we take into account the fact that not all passengers do travel across the entire session; but the price for transport in the individual sections is higher, and thus the revenues of the carrier will not be reduced. The revenues are calculated as the lowest possible revenues at a given occupancy. Profit is calculated as the difference between revenues and costs (Table 3).

Table 3 The Proposal of a Tariff on the Session Bratislava - Kosice for 100% Occupancy of the Model Train and the Costs of One Seat €12.0446 in the Entire Line

100% occupancy	TN		ZA		PP		KE	
	2. class	1. class	2. class	1. class	2. class	1. class	2. class	1. class
Bratislava	5	9	7	11	11	15	13	17
Trencin	.	.	3	7	8	12	10	14
Zilina	.	.	.	.	5	9	8	12
Poprad	.	.	.	.	.	.	3	7

Costs of one seat in the entire line are €12.0446.

Revenues: €6,846

Profit: €703.27

The prices for transport in individual sections are necessarily to be adjusted (raised) in order to cover the total costs also in case the occupancy is not 100%. Total costs are unchanged with respect to occupancy. The calculations with variable occupancy of the train are shown in the following Tables (Tables 4 - 9).

Table 4 The Original Tariff on the Session Bratislava - Košice for 80% Occupancy of the Model Train and the Costs of One Seat €15.0557 in the Entire Line

Original tariff with a lower occupancy (80%):

80% occupancy	TN		ZA		PP		KE	
	2. class	1. class	2. class	1. class	2. class	1. class	2. class	1. class
Bratislava	5	9	7	11	11	15	13	17
Trencin	.	.	3	7	8	12	10	14
Zilina	.	.	.	.	5	9	8	12
Poprad	.	.	.	.	.	.	3	7

Revenues: €5,476.8

Loss: €-665.93

Table 5 The Changed Tariff on the Session Bratislava - Kosice for 80% Occupancy of the Model Train and the Costs of One Seat €15.0557 in the Entire Line

Changed tariff with a lower occupancy (80%):

80% occupancy	TN		ZA		PP		KE	
	2. class	1. class	2. class	1. class	2. class	1. class	2. class	1. class
Bratislava	6	10	8	12	11	15	16	20
Trencin	.	.	4	8	10	14	12	16
Zilina	.	.	.	.	6	10	10	14
Poprad	.	.	.	.	.	.	4	8

Revenues after the change of rates: €6,700.8

Profit after the change of rates: €558.07

Table 6 The Original Tariff on the Session Bratislava - Kosice for 60% Occupancy of the Model Train and the Costs of One Seat €20.0743 in the Entire Line

Original tariff with a lower occupancy (60%):

60% occupancy	TN		ZA		PP		KE	
	2. class	1. class	2. class	1. class	2. class	1. class	2. class	1. class
Bratislava	6	10	8	12	11	15	16	20
Trencin	.	.	4	8	10	14	12	16
Zilina	.	.	.	.	6	10	10	14
Poprad	.	.	.	.	.	.	4	8

Revenues: €5,025.6

Profit: €1,117.13

Table 7 The Changed Tariff on the Session Bratislava - Košice for 60% Occupancy of the Model Train and the Costs of One Seat €20.0743 in the Entire Line

Changed tariff with a lower occupancy (60%):

60% occupancy	TN		ZA		PP		KE	
	2. class	1. class	2. class	1. class	2. class	1. class	2. class	1. class
Bratislava	7	11	11	15	11	15	21	25
Trencin	.	.	5	9	13	17	15	19
Zilina	.	.	.	.	7	11	13	17
Poprad	.	.	.	.	.	.	5	9

Revenues after the change of rates: €6,555.6

Profit after the change of rates: €412.87

Table 8 The Original Tariff on the Session Bratislava - Košice for 40% Occupancy of the Model Train and the Costs of One Seat €30.1114 in the Entire Line

Original tariff with a lower occupancy (40%):

40% occupancy	TN		ZA		PP		KE	
	2. class	1. class	2. class	1. class	2. class	1. class	2. class	1. class
Bratislava	7	11	11	15	11	15	21	25
Trencin	.	.	5	9	13	17	15	19
Zilina	.	.	.	.	7	11	13	17
Poprad	.	.	.	.	.	.	5	9

Revenues: €4,370.4

Loss: €-1,772.33

Table 9 The Changed Tariff on the Session Bratislava - Košice for 40% Occupancy of the Model Train and the Costs of One Seat €30.1114 in the Entire Line

Changed tariff with a lower occupancy (40%):

40% occupancy	TN		ZA		PP		KE	
	2. class	1. class	2. class	1. class	2. class	1. class	2. class	1. class
Bratislava	11	15	16	20	11	15	31	35
Trencin	.	.	7	11	19	23	22	26
Zilina	.	.	.	.	11	15	19	23
Poprad	.	.	.	.	.	.	7	11

Revenues after the change of rates: €6,410.4

Profit after the change of rates: €267.67

The carrier may also modify tariff rates with respect to each day of the week according to the occupancy of the train, recapitulation is show in Table 10. From the analysis it is clear that if about 500 people travel in one train from Bratislava to Kosice, the price for transport would be around €13 per one person.

Table 10 Comparison of the Ticket Price on the Session BA – KE

Comparison of the Ticket Price between BA - KE	Own proposal							
	100% occupancy		80% occupancy		60% occupancy		40% occupancy	
	1. class	2. class	1. class	2. class	1. class	2. class	1. class	2. class
	17	13	20	16	25	21	35	31
	RegioJet							
	Purchase of a ticket one day in advance*			Purchase of a ticket on Friday*			Purchase of a ticket a week in advance*	
	Standard	Relax	Business	Standard	Relax	Business	Standard	Relax
	12.1-14	15.9-18.7	20.6-25.3	12.1-21.5	15.9-28.1	20.6-33.7	12.1-14	15.9-18.7
	ZSSK, a.s. (state carrier)							
	2. class	CLASIK RAIL PLUS						
	18.76	14.07						

*Ticket price depends on the time of travel during the day (5:33 AM, 11:33 AM, 5:33 PM)

5. Conclusion

Own costs in the railway sector are similarly as in the case of other modes of transport influenced by external and internal factors. Among the external factors we can include mainly fees for the use of railway infrastructure, energy prices, rental (lease payments) of locomotives, carriages and so on. Good predictions on the number of transported passengers and the occupancy of seats on the train are necessary in order to eliminate the risk from unoccupied capacity of the train and then it is possible to propose the tariff which can effectively eliminate this risk. The carrier may also modify tariff rates with respect to each day of the week according to the occupancy of the train. From the analysis it is clear that if about 500 people travel in one train from Bratislava to Kosice, the price for transport would be around €13.

The ticket price for the session BA - KE with the state carrier is currently €18.76 (full price, which is subsidised by the state); private carrier RegioJet offers the price from €12.1 to €33.7 for this session, however this price depends on three factors (the day of ticket purchase, travel time and the class of a carriage). In our proposal, which takes into account the risk from unoccupied capacity of a train, the ticket price is dependent on the occupancy of the train. In the case of 40% occupancy of the train, the ticket price in own proposal is lower than the price level with a private carrier in the highest class during the rush hour. At formation of the tariff policy it is important to take

into consideration the forecast of development of the number of passengers.

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THE PROBLEMS OF URBAN ROAD TRAFFIC MONITORING

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Abstract This article discusses the problems of urban road traffic monitoring and investigation. A brief description of a video system for the traffic observation is presented. As an illustration of it use, the density of a road traffic calculated from a video is given.

Keywords : traffic monitoring, traffic control, image processing, swarco.

1. Introduction

Road transportation plays an important role for each country. Yearly, it completes approximately 80% of freights and 75% of passenger transportation. Until recently, the problems of coordination and controlling the transport flows on the street-road network (SRN) were not used with high actuality. In conditions of not-so-high loads, the SRN functioned efficiently enough and their activity did not lead to serious shutdowns and service denials. During the last few years, the increasing number of automobiles and the mobilization of the population has led to a saturation of urban streets, which became a reason to re-evaluate the principles for controlling transportation flows [4,11] and requires special attention towards reconstructing the SRNs in order to improve their functionality. The yearly increase in transportation load of the networks leads to a decrease in the speed of the flow and the appearance of traffic-jams.

The appearance of the latter, even when there is a surplus of free passages, is due to the unclear and uncoordinated processing of traffic lights, which increases the length of vehicles in service queue at crossroads. When the conditions are similar to a traffic jam, the vehicle queue may not be able to fit into the time interval needed to traverse two consequent crossroads. This situation is known as network congestion [2], and leads to disturbances in the work regime of the previous crossroad's traffic lights. The main priorities in the organization of road traffic are the issues of controlling them in the conditions of a traffic jam [4,10]. They require special attention when developing new principles and control norms in high levels of auto mobilization and dense traffic flows, which require the solution of new civil engineering and technical tasks.

2. BASIC FLOW MONITORING INDICATORS.

Traffic monitoring plays an important role for increasing the efficiency of traffic flows through the SRN. The information received by it is of significant importance for deciding the placement of road signs, traffic lights, information labels, when evaluating the driver's behaviour, which also introduces a certain influence in the functionality of the SRN, and other factors. In order to interpret the results correctly, the classification and exploitation characteristics of the vehicles play an important role. Usually, the vehicles are divided into several categories – cars, trucks, buses, trams, motorcycles and bike. A useful criteria, which generalizes the exploitation characteristics is the mass-power ratio. It determines the rate of acceleration and stopping, which are important factors to take into account when designing the traffic lights' signal schemes, fuel economy readings and evaluating the ability of the flow to resume its movement after stopping [2].

When buses and trams are present in traffic, the time required for serving their stops also has to be taken into account. The latter varies with regard to the loading/unloading zone, the

number of passengers, the door configuration and the payment method. The presence of bicycles in traffic also requires special attention, as their drivers can execute various and often surprising maneuvers, unlike car drivers. The behaviour of pedestrians has a similar characteristic, and they are generally considered a factor in road traffic, due to the fact that the traffic light schemes have to be adjusted with regard to their mean velocity.

3. INDICATORS, DERIVED FROM THE TRAFIC FLOW MONITORING INFORMATION.

The flow load is an indicator which varies depending on the month, the day of the week and the hour. It depicts the social and economic activity in the area, served by the traffic. The variations in the load during the different days of the week depend on the type of the route on which the traffic is conducted. An important part in the process of analysing the passage ability is given to the maximum load in certain time intervals (rush hour). They are the most crucial interval of the route's function and require the greatest passage ability. The load during rush hour is not constant. It varies in different days and seasons and leads to the formation of long queues. The traffic distribution in directions and lanes in a given route is another important part in analysing the passage ability. During each hour, the traffic in a given direction can differ greatly from the traffic in another direction. A typical example is the urban radial streets, for which the level of balance of flows in directions can reach a ratio of 2:1. The directional distribution is not a statistical characteristic and varies with regard to years, hours of the day, days of the week and seasons.

As an example the one day traffic flow distribution captured among 8 till 14 o'clock from crossroad of Shipchenski prohod" blvd. and "Ivan Dimitrov" str. (in front of block 2 of IICT, BAS), is presented on figure1.

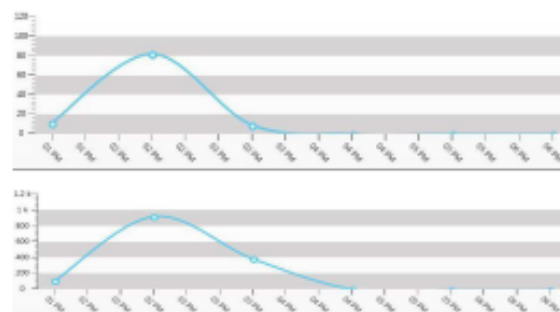


Fig.1. Distribution of the number of cars that have traversed the monitored area.

The distribution of the first week of june traffic flow passed through the same crossroad is shown on figure 2.

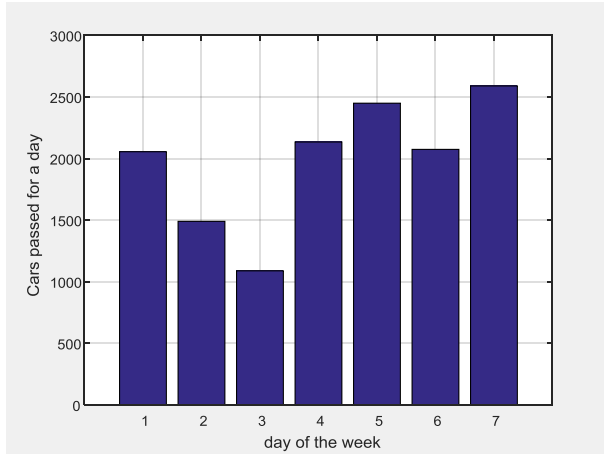


Fig. 2. The first week of june traffic flow distribution.

When the movement in one direction is conducted in 2 or more lanes, the traffic distribution varies greatly. Generally, it is dependent on the movement rules, the flow's speed and intensity, the number and placement of conduits, transportation routes and others. The passage ability is given in terms characterizing the maximum intensity of the flow, which can be served by the given road part in dominant conditions. Its direct monitoring is difficult due to the fact that fixing the maximum intensity of the flow for the given part does not guarantee that a high intensity flow will not be present at another time.

4. TRAFFIC CONTROL

In urban conditions the flow of vehicles can be considered continuous only in the segments between crossroads. A main role in the successful serving of these areas is given to traffic lights. In more cases, this mode of crossroad regulation is based on the principle of time division. Its use does not provide the necessary bandwidth, as they operate as a closed system in terms of the external environment and do not adapt to the changes of the road conditions.

A more modern and effective way to regulate intersections through traffic lights is adaptive control [3,8]. Their strategy offers a configuration according to the current road situation, depending on many factors, and allows for the introduction of a local intelligence traffic light that determines the dynamics of switching on the signal groups according to queue length and flow velocity [1,5,7]. A convenient approach to achieving optimization of a transport network according to the mode of transport traffic is the use of video information. It provides an opportunity to build an adaptive traffic control mechanism within a junction. Effective use of the obtained video information requires prior photogrammetric attachment of the observed stretch of the track with the observed image in the terms of the television broadcast standard. This ensures that correct performance of the operations intended to determine transport traffic parameters. A major drawback of video information systems is their dependence on light change and atmospheric conditions. When night or fog occurs, visibility and contrast in the image fall, which do not permits its reliable processing. The presence of rain or snowfall brings noise, which also reduces the contrast of the resulting image. Reduced

illumination can be compensated by signal amplification or an artificial illumination use. To reduce the glare from the road and the vehicles themselves, cast shadows and merging objects, the use of polarization and anti-infrared filters is a good approach. The introduction of control sections in certain areas of the frame to be analyzed also contributes to the reliability of the information retrieved from the incoming video stream.

Generally, to improve contrast and visibility, the processing of the received video sequence is done digitally within two interrelated stages.

At the first stage, an adaptive background assessment and threshold detection of fragments that have made changes that are inherent to moving objects are performed. In the second stage, the video frame is framed with fragments that have overcome a certain threshold using morphological processing. The execution of such processing is a sufficiently complex task, which can be presented in the form of several successively executable relatively independent operations:

- background assessment by tracking its changes;
- background compensation;
- threshold detection of moving fragments;
- Morphological processing using operations erosion, growth and opening;
- Fixing the crossing times of the control sections from the linked areas;

As the result of this calculation of the basic parameters of the traffic flow can be determinate. Late, based on them, the length of the traffic light cycle can be calculated. In its entirety the traffic control is a process which requires previous information. In order to achieve satisfying results in the carrying of this process, a setup was developed, which allows the monitoring and registering the traffic. The general appearance of the setup is given in Fig. 3.



Fig. 3. General appearance of the setup for traffic monitoring and registering.

As a registering device the IP Camera DCS-2330L was used[6]. The camera features a 1/4 "megapixel progressive CMOS sensor, a 3.45mm focal length and a waterproof IP65 housing, and features a built-in, infrared-free filter, a full-blown LED, and a built-in PIR motion sensor. It is equipped with H.264 compression, Motion JPEG, and 10 times digital zoom. Exposure time ranges from 1/7.5 to 1/10,000 sec. Supports a wide range of video resolutions,

interfaces to external Devices, and network protocols. It can be used with Microsoft Windows 8/7 / Vista / XP operating systems (see Fig. 4.).



Fig. 4. The IP Camera DCS-2330L

The camera is placed firmly on a vibration safe stand and connected to a PC. It is used to observe the crossroad of “Shipchenski prohod” blyd. and “Ivan Dimitrov” str. (in front of block 2 of IICT, BAS), shown in Figures 5. and 6. The images received from the camera are stored in the computer. As a main tool for their processing, the Matlab environment is used. Based on its image processing tools, the information for a current momentary condition of the traffic flow is extracted from the pictures obtained from the camera. . Later, this information is used to carry out an adaptive traffic light control. In order to improve the statistical robustity of the expected estimations, the information is averaged over a given time period. The averaged information is used to conduct an adaptive control of the traffic light connected to the swarco controller, shown in Fig. 7.



Fig. 5 Ivan Dimitrov str.



Fig. 6 Shipchenski prohod bul.



Fig. 7. ITC-2 Mini controller

5.CONCLUSIONS

This article presents a tool to monitor the density of traffic. Management of traffic light to control the measured density of traffic:

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LINE TRACK CAPACITY - ANALYSIS OF THE IMPLEMENTATION OF THE UIC 406 METHODOLOGY IN ŽSR CONDITIONS

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Abstract. A variety of A variety of methodologies are used across Europe for the estimation of railway infrastructure capacity. This paper introduces the basic principles of the analytical methodology (e.g. Slovak railways) and UIC methodology. On the basis of these new approaches, dependencies between occupation time and buffer time is researched. The aim is to compare the needed buffer time and its impact to the line capacity.

Keywords: CAPACITY, METHODOLOGY, TIME TRAFFIC DIAGRAM, BUFFER TIME, OCCUPATION TIME

1. Introduction

In the allocation of the capacity of train paths to railway undertakings, it is necessary for the infrastructure manager to know the capacity of the infrastructure. Defining the capacity of the railway infrastructure (transport route) is relatively difficult and there are many different approaches to its definition.

In view of the different concepts and procedures relating to railway infrastructure capacity and the subsequent calculations applied by railway infrastructure managers, the International Railway Union (UIC) has developed new one methodology. At the nowadays the various of methodologies across the Europe are used. The unification was done so that the results of the assessments on the corridors are reciprocally comparable. The UIC 406 Code, called "Capacity" [5], contains the adopted principles for detecting rail infrastructure capacity using of a compression method with IT support for these practices. Unlike theoretical concepts, the compression method is used in real-time schedules with practical measures and is designed to create a common basis for infrastructure capacity determination. In the second edition of the UIC Code 406 (2013), for the first time there is also a methodology for determining the capacity of stations and nodes based on the same principles. The UIC 406 Code is a recommendation, allowing to the infrastructure managers to use a national methodology for their own needs. [1]

Therefore the aim of the paper is to analyse the equivalence of the results determining the line capacity according to the UIC 406 Code recommendation and according to the applicable national methodology of ŽSR.

2. Methodology of capacity calculation according to national methodology ŽSR D24

In the Slovak infrastructure manager ŽSR, the methodology of the D 24 Regulation is applied, which establishes relations for calculating the quantitative and qualitative indicators of the capacity. [4]

Line practical capacity - n_{prakt} defined as practical throughput performance which is expressed by the number of trains for the defined time period.

$$n_{prakt} = \frac{T - (T_{vjzl} + T_{stai})}{t_{obs} + t_{medz}} \quad [vl.T^{-1}] \quad (1)$$

where the variables already referenced on the line (line section) are:

T – calculation time [min]

T_{vjzl} – total time in which the operating device within the computing time is barred from operation for prescribed inspections, repairs and maintenance [min]

T_{stai} – total time of permanent manipulations, i.e. the time in which the operating device is occupied by other actions than those for which throughput capacity is calculated [min]

t_{obs} – technological time of occupation by one train (or act) in which the throughput capacity is calculated [min]

t_{medz} – average buffer time for one average train [min]

As a result of this quantitative indicator, we evaluate the line practical capacity as well as qualitative indicators, which are in particular the infrastructure occupancy time rate - s_o and the usage of the line practical capacity K_{prakt} .

$$s_o = \frac{T_{obs}}{T - (T_{vjzl} + T_{stai})} \quad [-] \quad (2)$$

$$K_{prakt} = \frac{N_{prav}}{n_{prakt}} \cdot 100 \quad [\%] \quad (3)$$

where:

T_{obs} – total occupancy time of the line [min]

N_{prav} – total number of regular trains[vl.T⁻¹]

A sufficiently occupied train traffic diagram is considered that one with the infrastructure occupation rate of 0.5 to 0.67. The normative capacity is characterised with the usage of the line practical capacity K_{prakt} by the regular transport in the range of 80-90%. [4]

These qualitative indicators constitute an optimal limit between acceptable use of the infrastructure capacity and time reserves. These buffers are particularly necessary for compensation of delays in irregularities and failures in rail transport, as well as the reasons given in the literature [2] for the average additional times t_{dod} and the average time of probable interference of runs - $t_{truš}$. The average time of gaps for one average train (t_{medz}) is the parameter for evaluation and assuring the balance and also the quality of the train traffic diagram.

Recommendation of the ŽSR D 24 Regulation observes to a great extent to the line section character and the occupancy time. The average time of gaps for one average train t_{medz} deposit is recommended for operating conditions difficult (A), normal (B) and simple (C) depending on the occupancy time of the railway section by train. The list of recommended time of gaps is shown in Table 1.

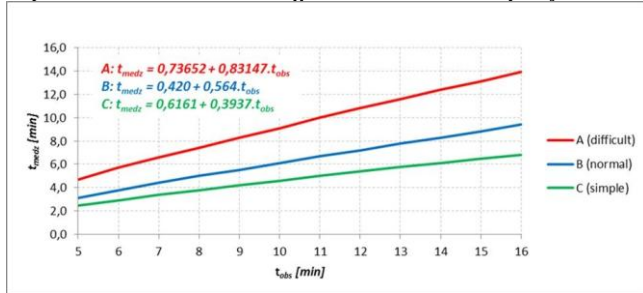
Table 1. Required buffer times t_{obs} [min] according to the Regulations of ŽSR D 24

t_{obs}	5	6	7	8	9	10	11	12	13	14	15	16
A	4,7	5,7	6,6	7,4	8,3	9,1	10,0	10,8	11,6	12,4	13,1	13,9
B	3,1	3,8	4,4	5,0	5,5	6,1	6,7	7,2	7,8	8,3	8,8	9,4
C	2,5	2,9	3,4	3,8	4,2	4,6	5,0	5,4	5,8	6,1	6,5	6,8

Source: [4], authors

Thus, it is evident from Table 1 that with the increasing t_{obs} , the value of the t_{medz} is increasing too, but the slower rate. This property can also be expressed graphically.

Graph 1. Correlation between buffer time t_{medz} and occupancy time t_{obs}



If the calculated value of the buffer time t_{medz} for one average train from the formula (1) is lower than the recommended value according to the ŽSR D 24 (Table 1), then there is a high risk of causing danger of the train traffic diagram quality disruption and its planned feasibility.

Capacity calculation methodology according to UIC 406 Code

Line capacity utilisation, referred to as "capacity consumption", is assessed on the line section and at defined calculation time according to this methodology.

$$\text{Capacity consumption} = \frac{\text{Occupancy time} + \text{Additional times}}{\text{Defined time period}} \cdot 100 \text{ [\%]}$$

In this case of UIC 406 Code formula, the optimal boundary between the use of infrastructure capacity and buffer time, it means the same as t_{medz} in the ŽSR D 24 methodology, is an additional time.

The criteria necessary for determining and assessing the "optimal" additional time are based on the operating characteristics of the existing train traffic diagram and actual delays, as well as in the case of time of gaps in the ŽSR methodology. However, extrapolation of time series may be time-consuming or impossible. For this reason, the standard value of the occupancy time rate was determined as an expression of the required level of services quality provided and is given in percentage expression:

$$\text{Occupancy time rate} = \frac{\text{Occupancy Time}}{\text{Defined Time Period}} \cdot 100 \text{ [\%]}$$

In the graphical process of the train paths compression, UIC 406 Code recommends the standard values of the occupancy time rate according to the type of train traffic on the line as follows:

Table 2. Recommended values of the occupancy time rate

Type of line	Peak hour	Daily period
Dedicated suburban passenger traffic	85 %	70 %
Dedicated high-speed line	75 %	60 %
Mixed-traffic lines	75 %	60 %

Source: [5]

Depending on the occupancy time rate, the recommended values of the additional time rate are given in the following table 3. It is derived from the occupancy time rate.

$$\text{Additional Time Rate} = \left[\frac{100}{\text{Occupancy Time Rate}} - 1 \right] \cdot 100 \text{ [\%]}$$

Table 3. Recommended values of the additional time rate for the types of line

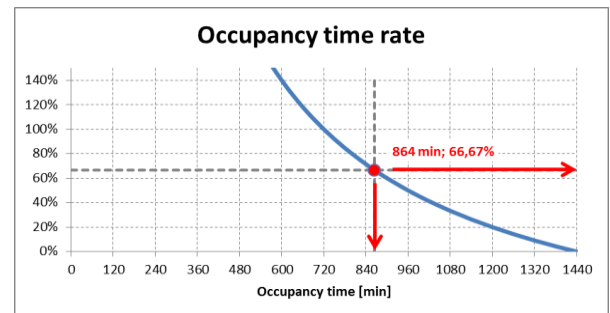
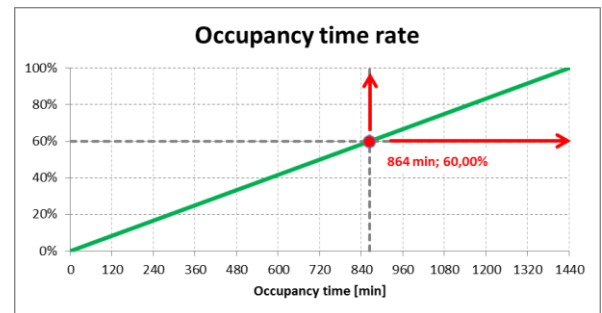
Type of line	Peak hour	Daily period
Dedicated suburban passenger traffic	18 %	43 %
Dedicated high-speed line	33 %	67 %
Mixed-traffic lines	33 %	67 %

Source: [5]

Capacity consumption values reflect the basic concepts of capacity expressed through the train traffic diagram features of individual train paths. Therefore they are used for bottlenecks identification. Therefore, the assessment of the capacity consumption (as well as the recommended weight between the occupancy time and the additional time) will be made according to the relationship:

$$\text{Capacity Consumption} = \frac{\text{Occupancy time} \cdot (1 + \text{Additional Time Rate})}{\text{Defined Time Period}} \cdot 100 \text{ [\%]}$$

Graph 2. Occupancy time rate



Source: authors

The occupancy time rate logically increases by the increasing of occupancy time. It is obvious from the formula (5). But there is evident from the formula (6) that with the increasing occupancy time the value of the additional time rate decreases. Thus, the dependence of the occupancy time rate and the additional time rate from the occupancy time at the constant defined time period can also be expressed graphically (see the graph 2)..

For the defined time period (1440 minutes), the recommended limits for mixed traffic lines(the majority) are indicated in the graphs 2 and 3 according to tables 2 and 3. The limit values and their direction, where the value is exceeded, are indicated red in the graph.

Overall, it can be assessed if the capacity consumption value is below the 100% limit, some of the line section capacity is still unutilised. Otherwise, if the recommended limit values are exceeded (for example Tables and graphs 2 and 3), there is a high risk of the causing danger of the train traffic diagram quality and its planned feasibility.

Comparison of methodologies through the calculations achieved

The presented methodologies for calculating and assessing of the line capacity use different calculation methods to achieve their results, although apparently different parameters are ultimately mutually comparable.

Therefore, the above mentioned methodologies will be referred in practical calculations. Their aim is to maximize the line capacity consumption (according to ŽSR practical capacity, according to UIC the capacity utilisation) using the maximum train paths, while the required quality and stability of the train traffic diagram is maintained. For both methodologies, the delimited time for capacity calculation is 24 hours (1440 minutes), and we do not expect to cut it off by T_{vijl} and $T_{stál}$.

Calculation of the practical capacity according to the methodology of ŽSR D24

If the occupancy time is $t_{obs} = 5$ min, and for a line with complicated ratios (A) is determined average time of gaps for one average train $t_{medz} = 4,7$ min, according to Table 1. Then the practical capacity according to formula (1) is:

$$n_{prakt} = \frac{1440}{5 + 4,7} = 148,45 \cong 148 \text{ trains during 24 hours}$$

Because it is done $T_{obs} = n \cdot t_{obs}$, then the infrastructure occupancy time rate s_o according to formula (2) is:

$$s_o = \frac{148 \cdot 5}{1440} = 0,514$$

The usage of the line practical capacity K_{prakt} converges to 100% (it is counted with the integer value of the trains number and not with the exact number). It can be verified with the following formulas (we put formula 3 into relationship 1 and modify it):

$$K_{prakt} = \frac{n \cdot (t_{obs} + t_{medz})}{T - (T_{vijl} - T_{stál})} \cdot 100 \text{ [%]} \quad (9)$$

$$K_{prakt} = \frac{148 \cdot (5 + 4,7)}{1440} \cdot 100 = 99,69\% \quad (10)$$

The all calculated values of these indicators for all occupancy times (t_{obs}) from Table 1 are as follows in the table 4.

Table 4. Calculation of indicators

t_{obs}	$n_{prakt} = N_{prav}$			s_o			K_{prakt}		
	A	B	C	A	B	C	A	B	C
5	148	177	192	0,514	0,615	0,667	99,69%	99,56%	100,00%
6	123	146	161	0,513	0,608	0,671	99,94%	99,36%	99,51%
7	105	126	138	0,510	0,613	0,671	99,17%	99,75%	99,67%
8	93	110	122	0,517	0,611	0,678	99,46%	99,31%	99,97%
9	83	99	109	0,519	0,619	0,681	99,72%	99,69%	99,92%
10	75	89	98	0,521	0,618	0,681	99,48%	99,51%	99,36%
11	68	81	90	0,519	0,619	0,688	99,17%	99,56%	100,00%
12	63	75	82	0,525	0,625	0,683	99,75%	100,00%	99,08%
13	58	69	76	0,524	0,623	0,686	99,08%	99,67%	99,22%
14	54	64	71	0,525	0,622	0,690	99,00%	99,11%	99,10%
15	51	60	66	0,531	0,625	0,688	99,52%	99,17%	98,54%
16	48	56	63	0,533	0,622	0,700	99,67%	98,78%	98,75%
average:				0,521	0,618	0,682	99,47%	99,45%	99,51%

Source: [4], authors

Calculation of practical capacity according to UIC 406 methodology

The UIC calculation methodology will be also applied to the same times of the line section occupancy. If there is the mixed traffic on the line, the recommended value of occupancy time rate is 60% according to Table 2 and the recommended value of the additional time rate is 67% during the day according to Table 3. Then, according to the formula (5), the value of the line occupancy time is [5]:

$$Occupancy\ time = \frac{Defined\ time\ period \cdot Occupancy\ time\ rate}{100} [min] \quad (10)$$

$$Occupancy\ time = \frac{1440 \cdot 60}{100} = 864\ min$$

Subsequently the additional time value is 576 minutes. It is possible to calculate the practical capacity from these values (similarly as in the previous methodology):

$$n_{prakt} = \frac{Occupancy\ time}{t_{obs}} [vl.T^{-1}] \quad (11)$$

$$n_{prakt} = \frac{864}{5} = 172,8 \cong 172 \text{ trains during 24 hours}$$

The average additional time t_{dod} for one train according to this methodology is:

$$t_{dod} = \frac{Additional\ times}{n_{prakt}} = 3,35\ min$$

$$t_{dod} = \frac{576}{172} = 3,35\ min$$

All calculated values of these measures for all occupancy times t_{obs} from the Table 1 are shown in Table 5. Comparison of the practical capacity calculated according to the UIC methodology and the ŽSR methodology is shown in this table in the differences between the routes, not only in quantitative expressions in number of routes, but also in qualitative expressions - percentage expression.

Table 5. Calculation of indicators

Mixed traffic line					Dedicated suburban passenger traffic				
t_{obs}	n_{prakt}	t_{medz}	paths differences		t_{obs}	n_{prakt}	t_{medz}	paths differences	
(min)	(path)	(min)	(path)	(%)	(min)	(path)	(min)	(path)	(%)
5	172	3,35	-5	97,18%	5	201	2,15	9	104,69%
6	144	4,00	-2	98,63%	6	168	2,57	7	104,35%
7	123	4,68	-3	97,62%	7	144	3,00	6	104,35%
8	108	5,33	-2	98,18%	8	126	3,43	4	103,28%
9	96	6,00	-3	96,97%	9	112	3,86	3	102,75%
10	86	6,70	-3	96,63%	10	100	4,32	2	102,04%
11	78	7,38	-3	96,30%	11	91	4,75	1	101,11%
12	72	8,00	-3	96,00%	12	84	5,14	2	102,44%
13	66	8,73	-3	95,65%	13	77	5,61	1	101,32%
14	61	9,44	-3	95,31%	14	72	6,00	1	101,41%
15	57	10,11	-3	95,00%	15	67	6,45	1	101,52%
16	64	10,67	-2	96,43%	16	63	6,86	0	100,00%
				96,66%					102,44%

Conclusion

There were practiced two capacity methodologies. Despite the different computation methods, their results are relatively similar. Current minor differences between the results of these methodologies are caused only by the limit of the acceptable line occupation time, limit of the required time of gaps. Practically, we can accept the UIC 406 and implement its methodology into national practices to estimate the practical capacity at ŽSR lines.

Acknowledgement

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VEHICLE PRODUCTIVITY IN NEW OPERATED RAIL-SERVICES

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Abstract: *For newly introduced transport services, there's not only the transport aspect that matters what the new service will bring to passengers, but also the operating costs are very important. In this area the systematic timetable planning plays an important role. Total costs of the transport system are significantly affected by the fixed costs, deriving from the number of regular deployed vehicles and drivers, related to the overall transport performance and total operational productivity. Advanced timetable engineering means a strong link between timetables, vehicles and infrastructure. The article demonstrates this approach on the example of the introduction of new express trains Praha - Plzeň - Cheb / München in the timetable 2017/18.*

KEYWORDS: RAILWAY TRANSPORT, PUBLIC TRAFFIC, RAILWAY TECHNOLOGY, TIMETABLING, OPERATION PRODUCTIVITY

1 Introduction

According to the data from Czech Ministry of Transport, passenger rail transport in the Czech Republic has been experiencing a great renaissance in recent years. The increase of passenger transport in passenger kilometers in 2010-2017 is 44%.

The main cause for this sustainable growth is in particular long-distance rail transport and suburban transport around great Czech cities (Praha, Brno, Ostrava, Plzeň).

Several factors contribute to the growth of demand. The first is improvement of the offer of connections, when the structural changes associated with the implementation of IPT (Integrated Periodic Timetable) between 2005-2009 brought about a fundamental change in the structure and frequency of supply, as well as in the creation of systematic links in IPT nodes. The second is undoubtedly shortening travel times associated with the modernization of transit railway corridors. The third major factor is the improvement of the fleet quality and the improvement of rail carrier services, which is also reflected in the liberalization of the passenger rail market.

Due to the increasing demand for transport and the progressive modernization of the infrastructure, the orderers of public transport react by expanding of timetable links and connections.

Czech Ministry of Transport, the orderer of long-distance passenger trains, has in the timetable 2016/17 introduced new express train segment between Praha - České Budějovice (- Linz) and follows in current timetable 2017/18 new express trains between Praha - Plzeň (- Cheb / München).

Increasingly, expanding transport performance requires productivity and efficient deployment of vehicles, so that these increases in traffic performance were generally financially manageable - both for carriers and for public authorities.

This approach to achieving operational productivity is demonstrated in the article on the example of newly established express trains on the line Praha - Plzeň.

2 Prerequisites for solving the productivity problem

In the Czech Republic, over a period of more than 20 years, intensive renewal of railway infrastructure, primarily transit railway corridors, has taken place. One of these cases is III. transit corridor leading from Cheb via Praha to Ostrava and to the border with Poland and Slovakia. Between Praha and Plzeň, the corridor is already completed at 62% of its length, including the longest newly built railway tunnel in the Czech Republic between Rokycany and Plzeň (tunnel Ejpvovice), which is 4.15 km long and should be completed and put into operation this year. Czech Ministry of Transport decided to order new express trains between Praha and Plzeň in the Timetable 2017/18, which

will be a new additional passenger service to the current fast trains.

The task was to prepare such an operational concept on the railway line, which would achieve the highest operational efficiency while respecting the boundary operating conditions.

These boundary conditions consist of the demand for reaching IPT nodes, the attraction travel time of newly introduced trains, the lack of travel time on existing trains and, last but not least, the current state of infrastructure. The final timetable is thus generated by repeated iterative steps associated with fine minute tuning, taking into account transport and operating parameters while maintaining the IPT principles.

At beginning, there's necessary to define the transport concept. Until timetable 2016/17, the operation of long-distance trains on the line Praha - Plzeň consisted only from fast trains, in which the Praha - Cheb trains were operated in 2-hour interval, in the 4-hour intervals trains Praha - München and in 4-hour interval trains Praha - Klatovy - all these lines together formed regular 1-hour interval between Praha - Plzeň.

All possible schemes of train paths have been verified as part of the search for acceptable variants. Under the terms of the periodic timetable, a solution that is symmetrical by minute 00 has always been sought.

The timetable constructional principle of the express train path was:

- 1) Examine the shortest travel time on infrastructure conditions with all constraints due to the reconstruction
 - 2) Time binding to a time position agreed for passing trains on the border with Germany
 - 3) From the above to derive the latest possible minute arrival to Plzeň (from Praha) and for this time to find the closest path, realizable periodically and symmetrically
 - 4) Overlapping of the time scheme of express paths (Ex trains) with the scheme of fast trains paths (R trains) and identification of technological collisions
 - 5) Solving the collisions primarily by adjusting the fast train (R) paths so, that the constraints of the existing connections in the IPT nodes are respected - the aim of the step was to make as few changes as possible for existing trains and linkages
 - 6) control of turn-over times of long-distance trains in end stations, prediction of turn-over times according to the planned works on corridor track, stabilization of the route
 - 7) Minute fine-tuning of express (Ex) and fast trains (R) paths in the Praha - Beroun section, within the exact time spacing of 30 minutes for collision-free timetable construction of suburban regional transport
- In the search for variants, it was always proceed first theoretically, by examining the mathematical conditions of the edge time lengths (in this case, the edge between the IPT nodes was replaced by an imaginary edge between the crossing stations) in the presence of both periodical segments in 1-hour period, by applying the edge equation

over the sums of 30 min within one segment and over the sums of 15 min within a combination of both segments.

Proposal of operational concept was verified by FBS - tool for timetable planning.

The new operating concept preserves only the line Praha - Plzeň - Klatovy as a fast train line with a larger number of train stops, while the lines Praha - Plzeň - Cheb and Praha - Plzeň - München are transformed into a new segment of express trains.

Classical long-distance fast trains (train category R) are operated in a basic interval of 120 minutes between Praha - Plzeň - Klatovy, and for most of the working day it is completed for 60 minutes interval between Praha - Plzeň. The long distance trains R are reaching wider IPT node 00 in Praha, the complete IPT node in Rokycany in the minute 30 and are bounded to IPT node 00 in Plzeň (from Plzeň to Klatovy is depart before the whole node). The suburban regional transport service at Praha is operated in a basic interval 30 minutes between Praha and Beroun. At the nearest agglomeration section between Praha and Řevnice the interval is concentrated in peak hours of working days to 15 minutes. The paths for long-distance fast trains are in the timetable so designed, to avoid overtaking regional trains in the section between Praha and Beroun, i.e. to avoid the loss of time for passengers in suburban transport. From this constraint it follows logically, that for the new express trains (train category Ex), the only path which could be used between Praha and Beroun is shifted exactly 30 minutes to the current fast trains. There should be found such path for the express train, which enables as possible to reach IPT node 00 in Plzeň. Thus, the entire timetable interval scheme of the Ex and R trains with regional trains had only such a time-manipulation space, to avoid disturbing current IPT nodes while avoiding overtaking regional trains. The conditions for the timetable construction of the path for new express trains were such, that a path with the smallest technological conflicts had to be found, which at the same time fulfilled the time conditions for passing trains on the border with Germany (for reaching transfer connections in stations Schwandorf, Regensburg and München). By express trains to Cheb, there were necessary to keep the existing IPT node 30 in Cheb. In total, there were introduced a 2-hour interval of direct express trains Praha - München and 2-hour interval of direct express trains Praha - Cheb, where both these 2-hour interval make together 1-hour interval of express trains between Praha - Plzeň.

Overall, this represents an increase of 55% transport performance, which is about 600 000 trainkm / year.

3 Operational productivity and efficiency

Productivity is generally defined as the ratio between the output of the enterprise and the necessary inputs. Since each output arises from a larger number of input variables, there is used in measuring the productivity of a larger number of partial indicators "partial productivity." Changes in output can not always be assigned to only one factor, and pursued partial productivity can not be seen as isolated endpoints and there should be monitored more parameters.

High productivity can be achieved through high efficiency and effectiveness. The effectiveness can be defined as a measure of how strongly the system output is produced in accordance with the desired output.

The efficiency can be described as the ratio between the produced output and input needed for its implementation (produced output / input). Some sources describe this difference clearly as "doing things right" (effective venue) and "doing the

right thing" (effective action). Effective action means: do the right thing at the right moment in time, while effective venue allows you to do these things with minimal resources.

Typical input quantities in the measurement of productivity in rail passenger transport are for example engines, engine-drivers or passenger cars. The offer in the timetable, expressed by train- or seat-kilometres means the produced output.

To assess (includes future) success of the TOC (rail carrier - Transport Operating Company), there is important to monitor important indicators for the assessment of productivity - there is seat km/car, train km/engine, train km/staff, train km/engine driver, seat km/train staff. They display, how well available resources are used to create an offer in the schedule.

Rail transport is specific to a generally high proportion of fixed costs. Variable costs are in terms of the Czech Republic about 60% of the level, when approaching a vehicle operating utilization of 80% (due to low travel speeds and thus small run over of vehicles). Such utilization in the Czech Republic is achieved usually on such lines, where it is consistently applied the IPT.

Certain costs of rolling stock, such as maintenance depend on the vehicle run over. These costs may be changed due to the implementation of measures to increase the productivity, although in comparison with the investment costs would be their impact rather small. These problems tend to magnify during major investment in the rolling stock. The acquisition cost of new rolling stock is comparable in the Czech Republic and abroad.

So the current approach described in chapter 2 applied by creating new transport concept is focused to offensive offer, where the existing resources in the field of rolling stock and staff are used to create higher level of service, while the growth of variable cost components must be covered by additional revenues.

4 Results

To ensure the original timetable concept, there were needed 9 engines with an average daily run of 683 km / day.

In the new timetable concept with considerable increase of the the transport volume, there had to be planned 4 additional engines, with enhanced productivity of the circulation, increasing the average daily run of the locomotive to 745 km / day. However, this state is only temporary, because after the opening of the Ejovice tunnel, the travel time of fast trains between Praha - Plzeň will be shortened by 7 minutes in each direction. The structure of the operational concept is so prepared, that at the same time will allow a quick turnaround of the engines in Praha. Average daily run of locomotives will thus rise to 806 km / day.

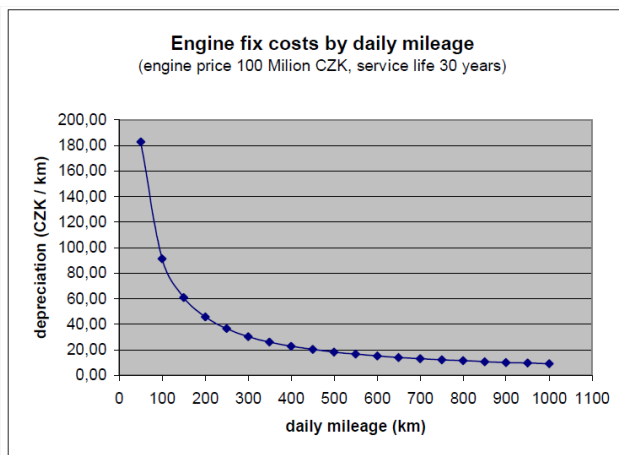


Fig. 1 Influence of the depreciation cost of the vehicle on transport performance depending on the traffic enforcement

Modern rail vehicle with a small mileage represents for each carrier an economic trap, since its operation by the usual amount of compensation (in the CR average 130 CZK / train km) isn't long financeable. The growth in vehicle productivity thus contributes to lowering the unit price of transport performance.

On fast trains and express trains, two-system locomotives of the type ČD 362 of the 1980s are currently deployed, but they will have to be gradually replaced in the following years by new engines. Even with regard to this future investment, it is still necessary to monitor the productivity of vehicles and to make any adjustments to the operational concept to interact between the timetable - vehicle - infrastructure.

From the point of view of reached travel times, the straightening looks as follows:

- travel time of fast trains (R) in periodic path in timetable 2016/17: Praha - Plzeň: 1 hour 37 min; Praha - Klatovy 2 hours 40 min; Praha - Cheb 3 hours 11min

- travel time of fast trains (R) in periodic path in timetable 2017/18: Praha - Plzeň: 1 hour 42 min; Praha - Klatovy 2 hours 38 min

- travel time of new introduced express trains (Ex) in periodic path in timetable 2017/18 Praha - Plzeň: 1 hour 25 min; Praha - Cheb 2 hours 54 min

It is obvious, that the only time-penalized passenger frequency is in the fast trains Praha - Plzeň, but in this relation the passengers are reaping the newly introduced express trains running every hour.

In the case of the fast trains Praha - Klatovy, the current travel time was hold. Connection to Cheb has become as part of new express service, and therefore there is significant time saving in this relation.

In the case of the international connection Praha - München, which is newly part of the introduced express segment between Praha - Plzeň, there was an increase in direct trains from 4 pairs to 7 pairs per day. Travel time in timetable 2016/17 ranged between 5 hours and 50 minutes to 6 hours, while in the 2017/18 timetable it was unified for 5 hours and 45 minutes.

5 Conclusion

This paper has presented, how timetable technological combinations could influence engine productivity in passenger rail services. All technological timetable processes and variants have been reviewed in the software FBS.

Since the beginning of creating the timetable concept, it is necessary to plan within the limits of interactions of the triangle timetable - vehicle - infrastructure and outside of it the transportation linkages take into account technological linkages and possible engine circulation between trains too. So an increase of the average daily run and of the productivity of the vehicles could be achieved.

This approach applied by introduction of a new express train segment between Praha - Plzeň led on one side to shorter travel times, on other side to increasing operational productivity.

From the point of view of travel times, there was found such solution, which by introducing new express trains (Ex) did not damage existing fast train segment (R), including its transfer links.

With further construction works, the constraints for train paths will also change and the technological solution founded for timetable 2017/18 is only temporary. While in the timetable 2017/18 the average daily run of the locomotives increased by 9%, the operational concept is prepared so, that by applying the same approach and methods will result in next increase of the average daily run in timetable 2018/19 by another 9% and in saving of one locomotive.

Advanced timetable engineering brings a strong contribution for an effective use of resources of TOC. Practical application of these tools makes necessary link between theory and praxis.

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EFFECTS OF PROPELLANT PROPERTIES ON INTERNAL BALLISTIC PERFORMANCE RESULTS OF SOLID ROCKET MOTORS

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Abstract: The aim of this research is to examine the effects of propellant properties such as: combustion temperature, propellant density, characteristic velocity, reference burning rate and burning rate pressure exponent on internal ballistic performance of solid rocket motors. A zero dimensional internal ballistic solver is developed and internal ballistic performance analyses of solid rocket motors having slotted cross section are performed. Thus, different internal ballistic results such as maximum combustion pressure, burning time, specific impulse and total impulse are determined. Finally, variation of these response variables according to solid propellant properties are determined constructing different response surfaces. Graphical results represented in this work makes easier to select solid propellants for a certain kind of geometrical configuration.

Keywords: SOLID ROCKET MOTOR, INTERNAL BALLISTIC PERFORMANCE, PROPELLANT, RESPONSE SURFACE

1. Introduction

During the design phase of a solid rocket motor (SRM), determination of the internal ballistic performance of the system has a special importance since this process enables to check whether the system requirements are satisfied or not. In order to analyze the performance of the system and to meet these requirements in a fastest manner, different researches on SRM design have been conducted so far. Açık, developed a tool to optimize thrust – time profile of a SRM by changing sectional parameters of the propellant coupled with nozzle dimensions [1]. Celegern developed a code to select best parameters providing desired internal ballistic performance with lowest possible mass [2]. In addition to geometric optimization studies which are conducted to find out the best propellant or SRM geometry, solid propellant selection process has also be taken into account meticulously. Therefore, effects of propellant properties on pressure – thrust curve and performance results based on this curve are examined for a constant SRM geometry using the response surface method. Internal ballistic performance analyses required to construct response surfaces are conducted using a zero dimensional (0D) internal ballistic solver which is developed in Matlab environment. Graphical results summarizing the effects of combustion temperature, propellant density, characteristic velocity, reference burning rate and burning rate pressure exponent on maximum combustion pressure, burning time, specific impulse, total impulse provide useful information that can be used during the design phase of the SRMs.

2. Solid Rocket Motors

SRMs are consist of motor case, insulation, igniter, nozzle and solid propellant. Sectional geometry of the propellant determines the burning behavior of it and so, shape of the propellant is selected in accordance with mission type of the system. Fig. 1 shows thrust – time profiles belonging to different propellant sections.

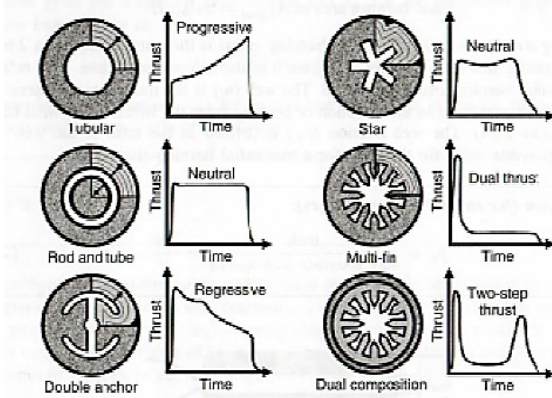


Fig. 1 Variation of thrust profiles according to propellant section [3].

Propellant type also affects the combustion pressure and thrust history of the system. Therefore, during preliminary design phase, propellant have to be selected so that its burning characteristics will satisfy the performance requirements of the mission without compromising from structural integrity of the propellant. It is significant to examine the effects of propellant properties on internal ballistic performance results to make better selections.

3. Internal Ballistic Performance Analysis

Development of Zero Dimensional Internal Ballistic Solver

Performance of a SRM can be analyzed using a zero dimensional (0D) internal ballistic solver. Thus, it is possible to determine pressure – time and thrust – time histories coupled with total impulse and specific impulse in the fastest manner. These kinds of practical solvers are widely used for optimization processes and they can also be used to provide results required to construct response surfaces.

In this work, a 0D internal ballistic solver is developed under the following assumptions. Combustion gasses are assumed as ideal gasses. Properties of combustion gases are not varying throughout the motor. Effects of erosive burning is neglected since aspect ratio of the analyzed propellant geometry is less than 5. Inertia of the combustion gasses is neglected. The flow through the nozzle is assumed as one dimensional, steady and isentropic. It is also assumed that burning rate (r_b) is varying in accordance with Saint Robert's burn rate law shown in equation (1) [4].

$$(1) \quad r_b = a \cdot P_c^n$$

Where, P_c is chamber pressure, a is burn rate coefficient and n is burn rate exponent. For a certain type of solid propellant, a and n are constant.

The 0D internal ballistic solver is based on the conservation of mass principle. Application of the principle constructs equation (2).

$$(2) \quad \frac{dP_c}{dt} = \frac{1}{V_i} \left[R \cdot T_c \cdot \left(\rho_p \cdot A_b \cdot a \cdot P_c^n - \frac{P_c \cdot A_t}{c^*} \right) - P_c \frac{dV_i}{dt} \right]$$

Where $dV_i/dt = A_b \cdot r_b = A_b \cdot a \cdot P_c^n$. Additionally, T_c is chamber temperature, R is universal gas constant, ρ_p is density of the propellant, A_b is burning surface of the propellant, A_t is throat area of the nozzle, c^* is characteristic velocity of the propellant and V_i is port volume. Since A_b and V_i are varying with time, these parameters are calculated performing burn-back analysis.

Solution of the equation (2) provides chamber pressure – time history of the SRM. In order to calculate thrust – time history, nozzle exit pressure (P_e) is calculated from equation (3) using nozzle dimensions and thrust coefficient (C_F) is calculated from equation (4) [4].

$$(3) \quad \frac{A_t}{A_e} = \left(\frac{\gamma+1}{2} \right)^{\frac{1}{\gamma-1}} \cdot \left(\frac{P_e}{P_c} \right)^{\frac{1}{\gamma}} \cdot \sqrt{\frac{\gamma+1}{\gamma-1} \cdot \left[1 - \left(\frac{P_e}{P_c} \right)^{\frac{\gamma-1}{\gamma}} \right]}$$

$$(4) \quad C_F = \sqrt{\frac{2\gamma^2}{\gamma-1} \cdot \left[\frac{2}{\gamma+1} \right]^{\frac{\gamma+1}{\gamma-1}} \cdot \left\{ 1 - \left[\frac{P_e}{P_c} \right]^{\frac{\gamma-1}{\gamma}} \right\} + \frac{P_e - P_{amb}}{P_c} \cdot \varepsilon}$$

Where, γ represents the ratio of specific heats, P_{amb} denotes ambient pressure, and ε represents the ratio of nozzle exit area to nozzle throat area (A_e/A_t). Finally, thrust (F), total impulse (I_{total}) and specific impulse (I_{sp}) are calculated using equations (5), (6) and (7) respectively [4].

$$(5) \quad F = C_F \cdot P_c \cdot A_t$$

$$(6) \quad I_{total} = \int_0^t F \cdot dt$$

$$(7) \quad I_{sp} = \frac{c^* \cdot C_F}{g_0}$$

Where, g_0 denotes gravitational constant.

Area under the thrust – time curve corresponds the total impulse which designates range of the system. On the other hand, the specific impulse is measurement of efficiency of the SRM. Therefore, during the design phase, it is crucial to satisfy the total impulse requirements with a motor having higher specific impulse.

Grain Burn-back Analysis

This study only investigates the effects of propellant properties on internal ballistic performance results. To do this, it is required to perform analyzes on a constant SRM geometry by changing propellant data. Fig. 2. represents the propellant geometry having slotted cross section and Table 1 contains geometrical dimensions of the propellant and the nozzle that are analyzed in this work.

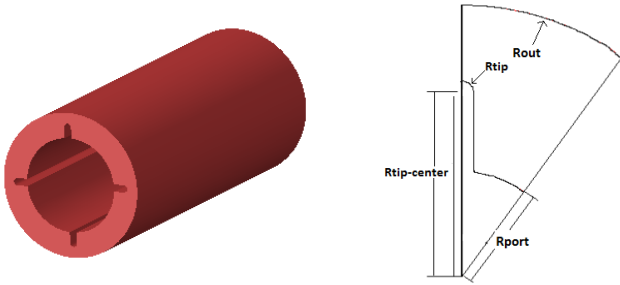


Fig. 2 Geometry of the analyzed slotted grain.

Grain burn-back analysis are required to determine the variation of A_b and V_i values with time. This information is required to solve the equation (2). Analytical, numerical and drafting techniques can be used to solve burn-back process. Since analytical method is the best method to calculate exact solution in the fastest manner for simple and some of the complex geometries, usage of analytical techniques are preferred during the burn-back solutions within the content of this work. Therefore, analytical burn-back equations are derived for the slotted grain geometry making geometrical calculations. Then, a solver working in Matlab environment is developed and validated with drafting techniques using a CAD software. Since derivation and validation of the burn-back solutions are beyond the scope of this work, further details are not presented in this research.

Table 1: Dimensions of the propellant and nozzle.

Symbol	Definition	Value	Unit
N	Number of slots	4	-
L	Propellant length	500	mm
R_{port}	Port radius	65	mm
R_{out}	Outer radius	100	mm
$R_{tip-center}$	Slot length	80	mm
R_{tip}	Tip radius of slot	5	mm
A_e/A_t	Ratio of nozzle exit area to nozzle throat area	4	-
A_t	Nozzle throat area	2800	mm ²

Validation of 0D Internal Ballistic Solver

Validation of the developed 0D internal ballistic solver is accomplished using both experimental and analytical results presented in Shekhar's work [5]. Same geometry is solved applying the same propellant data and geometry with Shekhar and results of the 0D internal ballistic solver is compared with Shekhar's analytical and experimental results (see Fig. 3).

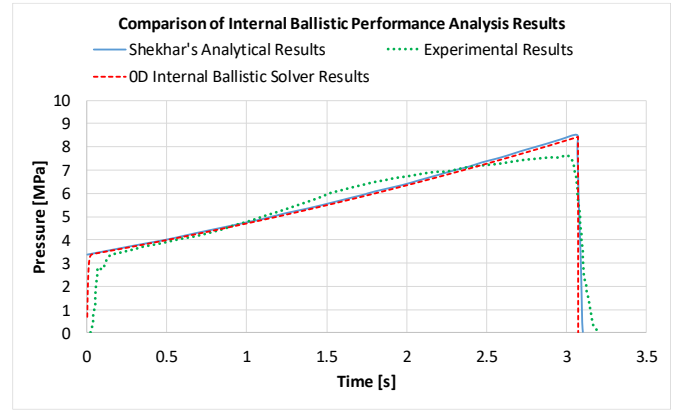


Fig. 3 Validation of 0D internal ballistic solver [5].

As it can be seen from the comparison that 0D internal ballistic solver results are same with Shekhar's analytical solutions which are quite good agreement with experimental results [5].

According to Sheikhleslam's work, if the aspect ratio (L/D) of a SRM is equal to 5 or lower than this value, neglect of erosive burning does not affect the accuracy of the solution [6]. Therefore, the aspect ratio of the design is set as approximately 3.85.

4. Response Surface Analysis

Response surface is a method used to determine detailed information about variation of a response variable with design variables. Response surface results has a special importance during preliminary design phase since they illustrate summarized information about which of the design variables have great importance on the response variable and how they are varying it.

The aim of the study is to examine the effects of propellant properties on internal ballistic performance results; so, combustion temperature, propellant density, characteristic velocity, reference burning rate and burning rate pressure exponent are defined as design variables and maximum pressure value during the burning process, burning time, total impulse and specific impulse are defined as response variables. Table 2 summarizes the boundaries of the design variables.

Table 2: Boundaries of the design variables.

Symbol	Definition	Lower Boundary	Upper Boundary	Unit
T_c	Combustion temperature	2000	4000	K
ρ_p	Propellant density	1500	2000	kg/m ³
c^*	Characteristic velocity	1300	1700	m/s
n	Burning rate pressure exponent	0.3	0.4	-
r_{b-ref}	Reference burning rate at 7 MPa combustion pressure	10	20	mm/s

Four different response surface analyses are performed. Each of them are constructed preparing full composite models consisting of 52 cases.

Response Surface of Maximum Pressure Value

Maximum pressure value (max. P_c) has a special importance on the SRM design since this parameter both designates thickness of the motor case and stress level on the propellant. Fig. 4 shows the percentage effects of propellant properties and interactions of them on maximum pressure value.

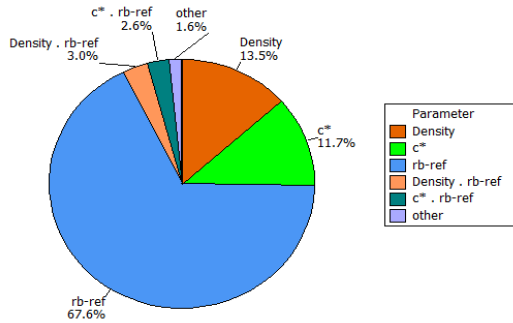


Fig. 4 Percentage effects of propellant properties on max. P_c .

According to the figure, r_{b-ref} has the greatest effect on maximum pressure value. Density of the propellant and c^* has also considerable amount of effect on it. Fig. 5 illustrates how these critical design parameters affect the magnitude of maximum pressure value.

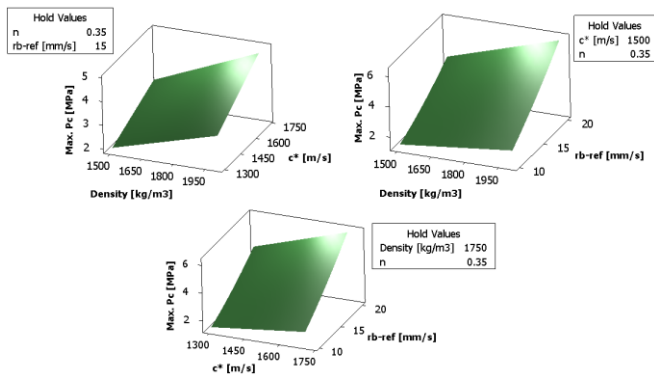


Fig. 5 Response surface results of max. P_c parameter.

According to the results, increment of reference burning rate, propellant density and characteristic velocity leads to increment of the maximum pressure value.

Response Surface of Burning Time

Duration of the thrust generation is another important issue, so, burning time of the propellant is a significant parameter. Fig. 6 shows the percentage effects of propellant properties and interactions of them on burning time.

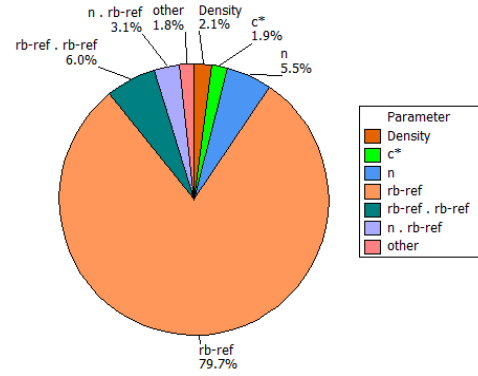


Fig. 6 Percentage effects of propellant properties on burning time.

According to the results, r_{b-ref} has the greatest effect on maximum pressure value. Additionally, burning rate pressure exponent (n) has also minor effects on the burning time. Fig. 7 illustrates the relationship among r_{b-ref} , n , and burning time.

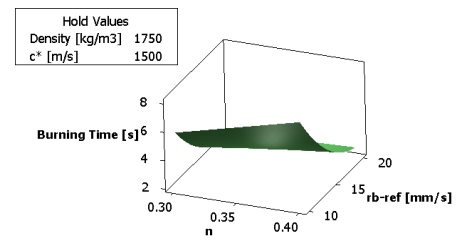


Fig. 7 Response surface results of burning time.

Results indicates that, increment of burning rate exponent increases the duration of the burning process. On the other hand, increment of reference burning rate leads to decrement of the burning time as expected.

Response Surface of Specific Impulse (I_{sp})

Specific impulse is main performance parameter that determines efficiency of a SRM. Therefore, this parameter is also quite significant. Fig. 8 illustrates the percentage effects of propellant properties and interactions of them on specific impulse.

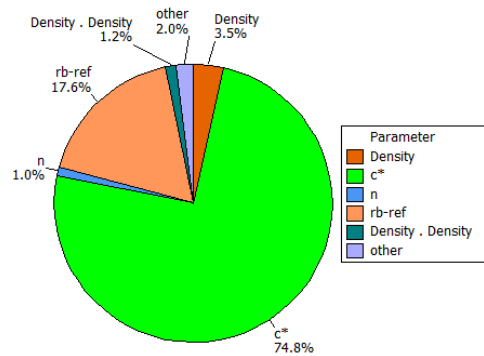


Fig. 8 Percentage effects of propellant properties on I_{sp} .

According to the results, characteristic velocity (c^*) has the greatest effect on the specific impulse. Additionally, reference burning rate (r_{b-ref}) has also considerable amount of effect on it. Finally, density of the propellant has minor effect on I_{sp} . Fig. 9 illustrates how these critical design parameters affect the magnitude of the specific impulse.

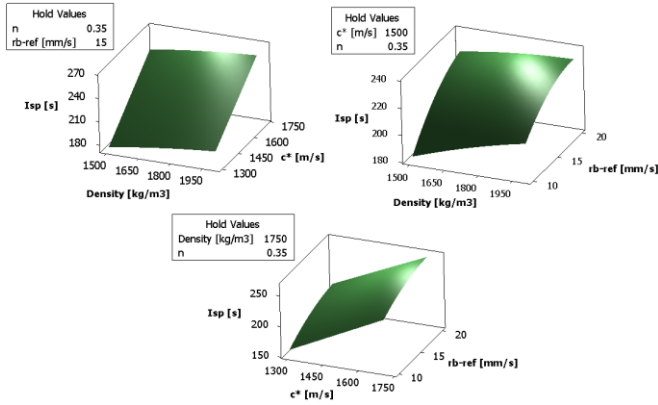


Fig. 9 Response surface results of I_{sp} .

According to the results, increment of c^* , rb_{-ref} and propellant density leads to more efficient designs by increasing the specific impulse of the system.

Response Surface of Total Impulse (I_{total})

Total impulse corresponds to area under the thrust – time curve. This parameter is quite important since there is a strong relation between the range of the rocket motor and itself. Fig. 10 illustrates the percentage effects of propellant properties and interactions of them on total impulse.

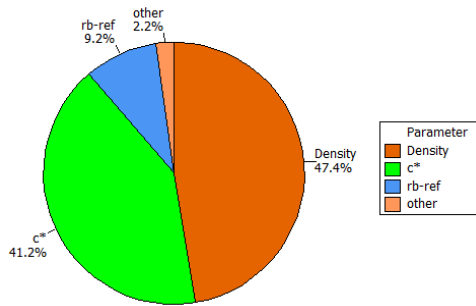


Fig. 10 Percentage effects of propellant properties on I_{total} .

According to the graph, propellant density and characteristic velocity (c^*) dominates the magnitude of the total impulse coupled with reference burning rate (rb_{-ref}) value. Fig. 11 shows how these critical design parameters affect the magnitude of the specific impulse.

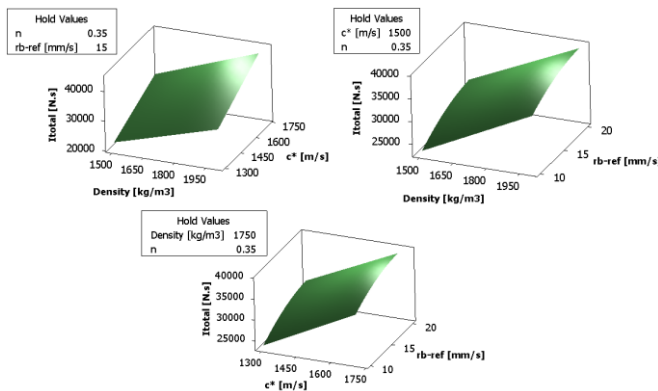


Fig. 11 Response surface results of I_{total} .

According to the results, increment of the propellant density, c^* and rb_{-ref} increases the total impulse value.

5. Conclusion

Within the content of this research, effects of propellant properties on internal ballistic performance results are examined performing response surface analysis. Performance analysis are accomplished using a zero dimensional internal ballistic performance solver that uses analytical burn-back equations.

According to the response surface results, reference burning rate (rb_{-ref}) has a great significance on burning time and maximum encountered combustion pressure value. Specific impulse that designates the effectivity of the propellant is strongly depend on characteristic velocity. On the other hand, total impulse of the system is dominated by propellant density and characteristic velocity of the propellant (c^*).

In addition to the main results, this work showed that usage of zero dimensional internal ballistic solver coupled with analytical burn-back solutions provides accurate results with very short amount of time that enables to accomplish many analyses required for construction of response surfaces. Finally, this study also revealed that designers could have detailed information about the behavior of design variables on response variables and it is possible to gain time during the preliminary design phase constructing response surfaces.

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IMPROVEMENT OF WHEELED TRACTOR'S REGULATOR IN DIESEL ENGINE

ПОДОБРЯВАНЕ РЕГУЛИРАНЕТО ДИЗЕЛОВИЯ ДВИГАТЕЛ НА КОЛЕСЕН ТРАКТОР

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Abstract: *On wheeled tractors it is expedient to erect the universal regulators, which can be set on singlemode regulation or multimode one, on the basis of serial multimode regulator 4 UTNM the key diagram, construction and manufacture design of research sample of universal multimode – singlemode regulator were worked out.*

The work is directed at raising of fuel economy and lowering of harmful rejections of wheeled tractor when performing transport work by using universal regulator and optimal partial high-speed characteristics under one-mode regulation.

Worked out mathematical model of the system "operator-tractor train-road" for investigating of influence of character of proceeding of partial high-speed characteristics of diesel engine on expenditure of fuel and harmful rejections of wheeled tractor. Investigations, conducted on this model, showed the advantages of one-mode regulation in the cases of work of diesel engine at variable modes. Inclination of partial high-speed characteristics under one-mode regulation essentially didn't influence on economical and ecological indices of wheeled tractor. By experimental investigations is confirmed the adequacy of mathematical model and checked the efficiency of experimental universal regulator.

KEYWORDS: UNIVERSAL REGULATOR, DIESEL ENGINE, WHEELED TRACTOR, FUEL CONSUMPTION, TOXIC SUBSTANCES

INTRODUCTION

Saving of liquid fuel and protection of environment from pollution with waste gases are crucial issues nowadays. Wheeled tractors used both in the field and in transport works are the main consumers of toxic fuels and sources of harmful ejections. The engines of such tractors are usually equipped with multimode regulators, which ensure maintaining a given rotation speed of a bent shaft in the whole effective range and automatically erect fuel feeding, depending on a loading. Use of these regulators is justified in field works, where maintaining a velocity of driving of a tractor in narrow borders is required. During transport operations, most of the time the engines work on transient behaviours at partial loadings. Reference for transient behaviours are often accelerations and decelerations of a tractor. At acceleration of a diesel engine with multimode regulator, the rail of the fuel pump sharply shifts on maximum feeding of fuel, and then, in accordance with increase of a rotational speed, is erected in a particular equilibrium position, defined by a loading, which should be overcome by the tractor. That is, the passage from one partial velocity performance to another is carried out through exterior velocity performance. As a result during acceleration of a tractor, at a combustor of a diesel engine the superfluous amount of fuel acts, causing its enlarged expenditure, increase of volume of smoke and toxicity of waste gases, and also excessively dynamic loads in transmission.

To remove these negative phenomena, taking place during transport operations, singlemode regulations can be used, with the maximum frequency of a reversion (regular is restricted to work only in one mode) and the possibility for the tractor operator himself is ensured to erect fuel feeding on partial conditions, immediately operating on a rail of the fuel pump. From this appears, that on wheeled tractors it is expedient to erect the universal regulators, which can be set on singlemode regulation during transport operations and on multimode one while working in the field.

RESULTS AND DISCUSSION

With participation of the authors, on the basis of serial multimode regulator of the fuel pump 4 UTNM the key diagram, construction and manufacture design of research sample of universal multimode-singlemode regulator (1) were worked out. It has following features: ensures the possibility of multimode or singlemode regulation; the passage to singlemode regulation is carried out by the fixing of a spring of the regulator in the stretched state, owing to that the spring of the regulator becomes a rigid segment and it enables immediately to operate on a rail of the fuel pump. The slanting character of partial velocity performances on a

site from a starting of a reversion to frequency, which answers a maximum torque, is ensured with a supplementary spring of a corrector, the previous strain of which is erected by a special cam depending on a position of a regulator's control bar. It is made for deriving constant exterior velocity performance both at multimode, and at singlemode regulating.

With the purpose of a functional test of the research universal regulator and the studies of its properties experimental examinations were carried out, involving engineless examination on the fuel pump and motor examination on a diesel engine D-240. In the first one, which was carried out on the stand KI-22205 for examination of the fuel equipment, velocity performances of fuel feeding were recorded (Fig.1) of the fuel pump with the universal regulator at multimode (Fig.1a) and singlemode regulations (Fig.1b). These performances represent associations cycle fuel feeding qcyc of the fuel pump from frequency of a reversion np of the pump's shaft.

As it is visible from these graphs, exterior velocity performances of the fuel pump with the universal regulator at multimode and singlemode regulations are identical. It is very important, as it enables the passage from one mode to another without changing the regulations of the fuel pump. The differences consist in substitution of partial performances. At singlemode regulation they transit more slantly.

For comparison of the basic indexes of a diesel engine D-240 at work with the universal regulator and different modes of regulation, the accelerations of an engine were carried out on the brake stand KI-4893. This on a fillet of the oscillography K12-22 rotational speeds of a bent shaft n, transition control bar of the regulator ϕ , rails of the fuel pump hp, and also acceleration time t_a of a diesel engine continuously were plotted a value of a torque M_k . The acceleration was carried out by transition control bar of the regulator from 100 up to 500 from a stationary value by its velocity in all cases of oscillographing. The outcomes of entries of the oscillograph testify, that at multimode regulation during acceleration the rail of the pump shifts to a maximum position, and is then erected precisely intermediate. That is, it come time is in a position, which answers operation on exterior velocity performance. At the expense of it the torque of a diesel engine will increase fan-in harder and the time of an exit is diminished by a terminating rotational speed on 2 sec. compared with acceleration at singlemode regulating. Eventually, relative transition of a control bar of the regulator replaces transitions of rails proportionally to transition of a bar. It enables to supervise overintensity of acceleration of a tractor in a greater measure.

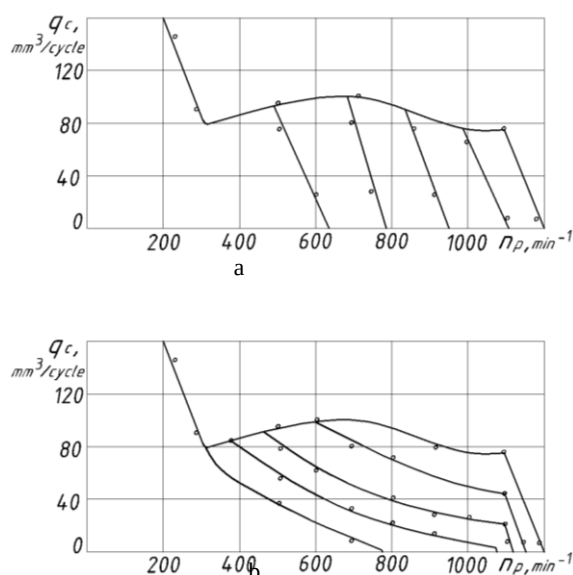


Fig. 1. Velocity characteristics of fuel feeding of the fuel pump 4 UTM with the research universal regulator at: a) multimode regulating, b) singlemode regulating

The analysis of influence of a regulating mode on an expenditure of fuel and toxic ejections of a diesel engine at transient behaviours of operation is made on a specially designed for this purpose mathematical model, in which the basic attention is given to acceleration of a tractor with the trailer. Acceleration in the model had on three stages: acceleration of a diesel engine in a condition of no-load operation; a breakaway of a tractor train from a place with skidded ganging and acceleration with interlocked ganging.

In the mathematical model of a diesel engine, regulator of a rotational speed, main part of ganging and driving of a tractor train are described by systems of differential equations, all other composite models are described by the algebraic equations. An expenditure of fuel and air, ejections of toxic substances are described by polynomials of the second order. For a solution of systems of differential equations a Runge-Kutt-Feldberg' method was selected. The calculations were carried out on a personal computer in conditions of acceleration of a tractor train (tractor MTZ-80 with the trailer 2-PTS-855) with a rated load with a coefficient of resistance to wheels' rolling $f = 0.0126$. For comparison of indexes of acceleration at multimode and singlemode regulation the frequency of a bent shaft' reversion at the end of acceleration on each for both modes of regulation took root identical and equaled 1500 min^{-1} .

In Fig.2 the outcomes of the theoretical rating examinations on mathematical model, namely influence of control bar's position of the regulator during acceleration on ejections of toxic substances and fuel of a tractor MTZ-80 are shown at different modes of regulation. Continuous lines show the relation of time t_a , route s_a to ejections of toxic substances: oxides of nitrogen and carbon, hydrocarbons and soot (g_{NOx} , g_{CO} , g_{CH} , g_C) and expenditure of a fuel g_f at acceleration up to a velocity 6,5 m/sec for the position of regular control bar at singlemode regulation. Dotted lines show the same indexes at multimode regulation. As can be seen from relations, even for accepted limitations on frequency of a reversion at the moment of switching gears during acceleration, the application of singlemode regulation considerably widens the possibilities of a tractor operator to supervise overintensity of acceleration of a tractor train with the purpose of saving fuel and reduce pollution of environment. For the phase of acceleration by partial transition of a regulator' bar, the singlemode regulation enables, increasing the acceleration time by 24.4%, to lower ejections of toxic substances with exhaust gases: for CO up to 49.7%, for CH up to 44.4%, for NO_x up to 16.5%, for soot up to

54.6% and to reduce an expenditure of fuel by 23.3%. At sharp complete transition of a bar economics, dynamic indexes and toxic ejections at regulation are identical.

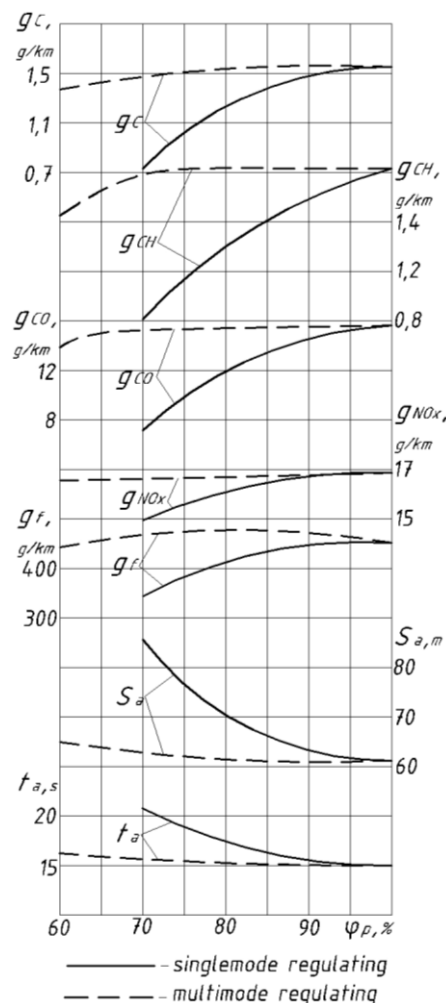


Fig. 2. Influence of control bar's position on ejections of harmful substances, expenditure of fuel, route and acceleration time of tractor MTZ-80 with the trailer at different modes of regulating

Nowadays the reduction of toxic ejections by wheel tractors is essential in the countryside, where they usually are exploited, as the rise of atmospheric pollution as well as ground and pools poisoning is increasingly observed there. It is proved, that the rate of such toxic substances as oxides of nitrogen, carbon, hydrocarbons, soot in the atmosphere at work sites and in cabins of tractors can at times exceed standard norms. And it badly affects a worker's health. It must also be mentioned, that engineering works are often conducted near human habitations, and wheel tractors work frequently also in enclosed locations, serving cattle-breeding farms, hothouses, storehouses etc.

The adequacy of the mathematical model during acceleration of a tractor train was tested comparison of calculated indexes, which characterize mode of operations of a diesel engine (position of a bar of the regulator and rails of the fuel pump) and dynamic indexes of a tractor train (velocity of a tractor and acceleration time) with the experimentally obtained ones.

The experimental glow irises were obtained by a continuous entry of the designated indexes on a fillet of the magnetoelectric oscillograph K 12-22, using thus the block of scale amplifiers and transmitters – rheostatic for fixing transition of a bar and rails of the fuel pump, and tachogenerator for definition of a rotation speed of a driving wheel, which was then enumerated in a velocity of a tractor.

The engine steadily worked in all conditions both at multimode and singlemode regulations, and the switching from one mode to another was carried out from the tractor's cabin.

On the whole, the results of the carried out examinations prove the expediency and possibility of the application of universal multimode-singlemode regulators on diesel engines of wheeled agricultural tractors.

CONCLUSIONS

On wheeled tractors it is expedient to erect the universal regulators, which can be set on singlemode regulation or multimode one, on the basis of serial multimode regulator 4 UTNM the key diagram, construction and manufacture design of research sample of universal multimode – singlemode regulator were worked out.

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EFFECT OF FUEL ADDITIVES ON DIESEL ENGINE PERFORMANCE AND EXHAUST EMISSIONS

ИССЛЕДОВАНИЕ ВЛИЯНИЯ ТОПЛИВНОЙ ПРИСАДКИ НА РАБОТУ ДВИГАТЕЛЯ И ЭМИССИЮ ОТХОДНЫХ ГАЗОВ

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Abstract: The performance and combustion emissions of diesel engine can be modified using various chemical fuel additives. Fuel additives consist of a variety of chemical compounds. It contains chemical elements such as: hydrocarbons, C11-C14, C10-C13, n-alkanes, isoalkanes, cyclics aromatics, cycloalkane, 2-ethylhexyl nitrates. Analysis has been conducted on diesel fuel and diesel fuel and additives blends. Fuel additives No.1, No.2 and No.3 consisting of these chemical elements have been analysed. The obtained results show, that the amounts of carbon monoxide emissions at low engine loads (IMEP = 0.32 MPa) increases up to 35% compared to pure diesel fuel. While using additives, the hydrocarbons emissions at low engine loads almost doubles compared to pure diesel fuel. The break specific fuel consumption with the engine powered by pure diesel fuel was lowest in all modes. The highest increase on in cylinder pressure 11% was only determined with the fuel additive No.3 at the maximum load of 1.12 MPa at the speed of 1800 rpm.

KEYWORDS: FUEL ADDITIVES, EXHAUST EMISSIONS, INDICATED MEAN EFFECTIVE PRESSURE, HYDROCARBONS, N-ALKANES, CYCLOALKANE, 2-ETHYLHEXYL NITRATE, NAPHTHALENE

1. Introduction

Vehicles with internal combustion engines typically use petroleum-based fuel. In internal combustion engines, these fuels release thermal energy which is converted into work. During combustion, petroleum products release carbon monoxide (CO), carbon dioxide (CO₂), hydrocarbons (HC), nitrogen oxides (NO_x), particulate matter (PM). These chemical compounds contribute to environmental pollution and increase the greenhouse effect. High environmental contamination changes the living conditions of people, affects the health of biological organisms.

Combustion emissions of internal combustion engines can be reduced by various measures. However, combustion emission neutralisers, catalytic converters and particulate filters have their own limits and today their technical capabilities have reached their limit. To reduce emissions of combustion products, it is possible to use alternative fuels, optimize combustion processes, use fuel additives and other sources of energy such as electricity or hydrogen.

At the petrol stations or automotive parts' stores, the supply of various additives is quite high. According to manufacturers, fuel additives optimize the combustion process, reduce the number of harmful particles in combustion emissions, cleanse the engine from pollutants, and provide additional functions improving one or another property of the fuel.

The fuel additives, which are intended to optimize the combustion process typically has following chemical elements: hydrocarbons, C11-C14, C10-C13, n-alkanes, isoalkanes, cyclics aromatics, cycloalkane, 2-ethylhexyl nitrates. The amount of these elements varies in each additive depends on its manufacturer, while their actual composition is not disclosed. Only the approximate composition is provided in the safety data sheets.

The alkanes used in fuel additives are organic compounds composed of carbon and hydrogen atoms. The use of alkane compounds in fuel impacts on autoignition delay period. This autoignition delay time depends on the gas pressure in the cylinder and the air surplus ratio. The autoignition delay time is to be understood as the period during which the temperature of the air-fuel mixture rises from the initial to 400 K [1]. Shorter autoignition delay time of fuel leads earlier beginning of the to the combustion process in the cylinder. This increases the heat release rate and pressure in the cylinder. These factors reduce the level of smoke, carbon monoxide, and hydrocarbons in the combustion emissions. A negative effect – increased nitrogen oxide emissions.

Researchers have long known about the 2-ethylhexyl nitrate additive of diesel fuels, which improves the entire combustion

process. The primary effect of the 2-ethylhexyl nitrate additive is to accelerate the preignition radical-pool formation, thus shortening the autoignition period. This effect is most significant at the lowest gas temperature-density conditions and least significant at the highest temperature-density conditions [2]. The observations support the arguments that 2-ethylhexyl nitrate decomposes very early in the spray development and enhances the earliest phases of the radical pool formation leading up to ignition and combustion. The later stages of the radical pool formation are controlled by the parent fuel chemistry, and are not similar like to a fuel which has the same natural cetane number [2].

The most commonly used for this purpose is the 2-ethylhexyl nitrate, which can improve the combustion characteristics, shorten ignition delay and decrease the burning point. The primary effect of the additive is to initiate early formation of a radical pool by providing an efficient mechanism for hydroxyl production [3].

When assessed in terms of performance, diesel fuel has the maximum value of average brake torque and brake power compared with other fuels. Addition of 10% ethanol, 2% 2-ethylhexyl nitrate in to diesel fuel, increased the cetane number by 5.45% in comparison with mixture of 10% ethanol and 90% diesel. Whereas 2-ethylhexyl nitrate has caused a slight decrease in kinematic viscosity, lower heating value and a slight increase in density [4].

Mixing of various chemical additives or their compounds in diesel fuels might change fuel properties and combustion chemical reactions. It changes the speed of chemical reactions, combustion temperatures and at the same time combustion emissions. The increase in chemical additives in fuels is limited by factors having both positive and negative impact. Fuel additives affect the cetane number, viscosity, and pour point of diesel fuel. Some chemical elements are volatile and if kept for a long time, they simply evaporate from the fuel.

2. Preconditions and means for resolving the problem

The stand test was performed at the Engine Testing Laboratory in the Institute of Power and Transport Machines, Faculty of Agricultural Engineering, of Aleksandras Stulginskis University, Turbocharged, four-stroke, four-cylinder, common rail (CR), direct-injection (DI), diesel engine (FIAT 1.9 JTD 8V) with a swept volume of 1.9 dm³ and compression ratio of 18:1 was used for the experiment. The schematic view of the test stand, equipment, and apparatus used for the experiments shows Fig. 1.

Air consumption was measured with AVL Sensyflow P14243 ± 0.25% measuring system. The engine torque was measured by using

a three-phase asynchronous 110 kW AC stand dynamometer KS-56-4 with a definition rate of ± 1 Nm. The engine revolution was measured by using the AVL crank angle encoder 365C mounted at the front end of the crankshaft that guaranteed an accuracy of less than $\pm 0.2\%$ of measured value. A high-speed multichannel indicating system, consisting of the AVL angle encoder 365C and high-performance pressure transducer GU24D coupled to the AVL microFEM piezoelectric amplifier and signal acquisition platform IndiModul 622, connected to PC was used. PC was equipped with the AVL IndiCom Mobile software which was used for the recording, acquisition, and processing of fast crank-angle gas pressure signals in the first cylinder. A piezoelectric uncooled transducer GU24D with the measurement range of 0 – 280 bars were used to measure gas pressure for every load-speed setting point with an accuracy of ± 0.1 bar within the temperature range of 25 °C to 200 °C. The crank angle was recorded by using the AVL encoder 365C with an accuracy of $\pm 0.1^\circ$ CAD.

Thus, the heat release characteristics were calculated by using a single cycle diagram of the in-cylinder pressure versus crank angle as the input data average over the 100 subsequent combustion cycles, instantaneous cylinder volume and their first order derivatives with respect to crank angle. The data post-processing software AVL Concerto advanced edition was used to improve productivity and accuracy of the test results.

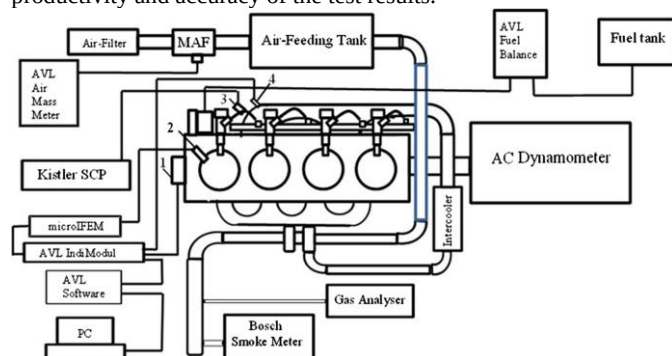


Fig. 1. Schematic arrangement of the engine test stand (1) AVL crank-angle encoder; (2) piezoelectric in-cylinder pressure transducer; (3) fuel high-pressure line transducer at the injector; (4) air boost pressure sensor in the intake manifold.

Emissions of nitric oxide NO (ppm), nitrogen dioxide NO₂ (ppm), carbon monoxide CO (ppm), carbon dioxide CO₂ (vol. %), and total unburned hydrocarbons HC (ppm) were measured with Test 350 XL flue gas analyser. The total nitrogen oxides NO_x was calculated as a sum of both the NO and the NO₂ components with an accuracy of ± 5 ppm. The smoke density (%) was measured with a “Bosch” RTT 110 opacity-meter, readings of which are provided as Hartridge units (% opacity) in a scale range of 0-100% with an accuracy of $\pm 0.1\%$.

The properties of the tested fuel are presented in Table 1. A fossil diesel fuel (DF) and additives in diesel fuel No.1 (which contains hydrocarbons, C11-C14, n-alkanes, isoalkanes, cycloalkane, 2-ethylhexyl nitrates), No.2 (alkyl nitrate, kerosine (petroleum), hydrodesulfurised naphthalene, odourless kerosene, solvent naphtha, heavy aromatic), and No.3 (Di-tert-butyl peroxide, hydrocarbons, C10-C13, n-alkanes, isoalkanes, cyclics aromatics) were used in this study. The structure of the fuel additives is presented in Table 2.

Table 1: The diesel fuel properties

Fuel Property	Diesel	Standart
Kinematic viscosity at 40 °C, mm ² /s	2.65	LST EN ISO 3104
Density at 15 °C, kg/m ³	841.3	LST EN ISO 3675
Flash Point, °C	56	LST EN ISO 2719
Cetane number	51.3	LST EN ISO 5165
Lubricity (HFRR), μ m	401	LST EN ISO 12156-1
RME, %	6.69	LST EN 14078

3. Solution of the examined problem

The purpose of the research was to investigate the effect of fuel additives (No.1, No.2 and No.3) on engine performance and exhaust emission characteristics.

During the experiment, the key controlled parameters were the torque and the revolutions of the engine's crankshaft. The load characteristics of the engine were taken at 1800 rpm and 2200 rpm. The engine has been loaded with a dynamometer stand KS-56-4 at constant torque modes by 49.05, 88.29, 117.72, 147.15, 176.58 and 206.01 Nm. Were calculated to the mean effective pressure (IMEP): 0.32, 0.50, 0.62, 0.78, 0.94 and 1.13 MPa. In this case, of engine loads and crankshaft speeds the fuel consumption and exhaust emissions were measured. The coolant liquid and lubricating oil temperatures were within the range 80 – 85 °C.

Table 2: The structure of fuel additives [5, 6, 7]

Name	Volumetric Volume %
No.1	
Hydrocarbons, C11-C14, n-alkane, isoalkanes, cycloalkanes	50 – 100
2 – ethylhexyl nitrates	5 – 10
No.2	
Alkyl nitrate	5 – 10
Kerosine (petroleum) hydrodesulfurised	1 – 5
Naphthalene	< 1
Odourless kerosene	60 – 100
Solvent naphtha, heavy aromatic	1 – 5
No.3	
Hydrocarbons, C10-C13, n-alkanes, isoalkanes, cyclics, aromatics	75 – 90
Di-tert-butyl peroxide	5 – 10
Solvent naphtha, heavy aromatic	1 – 2.5
Naphthalene	0.1 – 1

The mineral diesel fuel and additives blends was prepared according to the provided instructions. The proportion of the mixed blends used in the test presented in table 3.

Table 3: Proportion of mixed blends [5, 6, 7]

	Diesel fuel	Additive
No.1 Blend	80 liters	250 ml.
No.2 Blend	60 liters	200 ml.
No.3 Blend	70 liters	325 ml.

All collected data was processed and saved by AVL IndiCom software. The single-cycle and summarized over 100 consecutive cycles the in-cylinder pressure versus crank angle were recorded for every 0.10 crank angle degree (CAD).

The exhaust emission was estimated as an average value measured over the 25 - 30 seconds of the engine combustion process. In this time interval, the data was fixed every second and average of obtained results was calculated.

At the constant engine load and crankshaft rotation speed, the consumption time of the supplied fuel amount was measured three time, with each measurement performed in 30 seconds. From these results, fuel mass consumption and brake specific fuel consumption was calculated.

4. Results and discussion

When the engine is running at relatively low load (0.32 – 0.5 MPa) and rotation speed of 1800 rpm the emission of carbon monoxide values was the highest by 170 – 204 ppm in case of using diesel fuel. Using diesel fuel and additives No.1, No.2 and No.3 blends, the emissions of carbon monoxide emissions values, produced by the engine was 108 – 182 ppm. After the engine load increased to 0.55 MPa and 0.9 MPa, the situation has changed. The lowest CO emission of 100 ppm was obtained by working on a normal diesel fuel. For the diesel fuel and additives blends were higher by 35% respectively. At higher load (0.9 – 1.12 MPa), the CO emission values increased to 202 - 356 ppm.

When the engine was working throughout the load range the emission of unburned hydrocarbons was the lower in case of using

normal diesel fuel (Fig.2). The HC emission has changed from 537 to 682 ppm. When the engine operates on diesel fuel and additives No.2 blend, HC emission values have been rising from 773 to 875 ppm. The higher HC values have been produced from 841 to 1115 ppm, when the engine was operating on the diesel fuel – additives No.1 and No.3 blends.

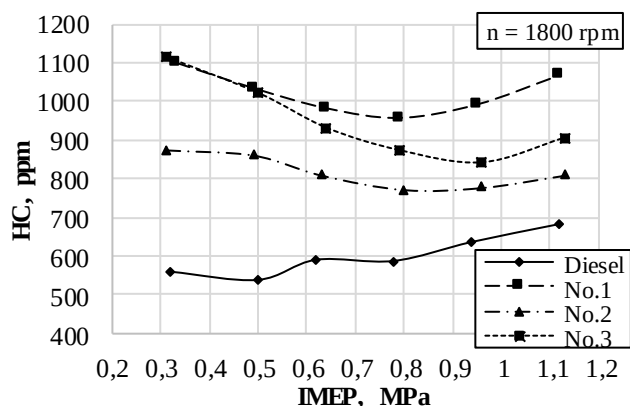


Fig. 2 Emissions of unburned hydrocarbons HC as a function of engine load (IMEP) at 1800 rpm

The highest NO_x concentrations have been observed at the increasing load of the engine in case of using diesel fuel and diesel fuel - additives blends (Fig.3). The factor that may have influence on the increase of nitric oxide emission is the rising average gas temperature in cylinder. At low load (IMEP = 0.35MPa) and 1800 rpm, the higher gas temperature in cylinder was 1660 K. After reaching the maximum engine load (IMEP = 1.2 MPa) the gas temperature in cylinder increasing by 2495 K.

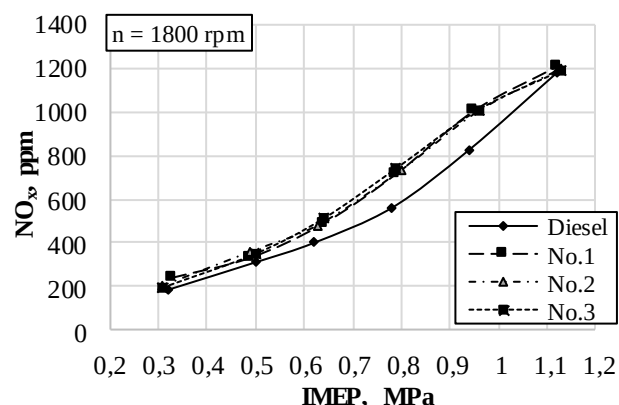


Fig. 3 The nitrogen oxides emission produced from DF and different fuel additives as a function of engine load (IMEP) at 1800 rpm

When the engine was running at relatively low load (IMEP = 0.32 MPa) and speed of 2500 rpm, the emission of carbon monoxide produced from diesel fuel - additives blends were the highest values from 291 – 403 ppm. At rising the maximum engine load, the CO emission values decreased to 89 – 123 ppm.

The lowest HC emission values from 844 to 747 ppm has been received on the pure diesel fuel. The higher HC value from 1081 – 1054 ppm has been produced, when the engine operated on diesel fuel and additives No.1 blend.

The total emission of nitrogen oxides normally scales up when load of engine increases. Such the NO_x emission behaviour completely corresponds with the estimations of fundamental theory of the internal combustion engines. The behaviour of the emission of NO_x with load and their changing tendencies remained more or less the same when the engine was running on the low engine speed. When the engine is running on low load (IMEP = 0.32 MPa), the NO_x emissions ranged values from 366 to 426 ppm. In case of medium engine load (IMEP = 0.5 MPa), the NO_x emission level decreased values to 179 - 249 ppm. When the diesel fuel and diesel fuel - additives blends are used and the engine load was increased, the NO_x emissions values continue rising to 862 - 934 ppm.

The highest brake specific fuel consumption was obtained at the low engine load (0.32 MPa) at 1800 and 2500 rpm speeds (Fig.4). In case the engine load increases, the brake specific fuel consumption is gradually decreasing. Using the diesel fuel and additive blends, the brake specific fuel consumption increased. When the engine is running on 2500 rpm at full load, the brake specific fuel consumption is equal to diesel fuel. At high engine load (IMEP = 1.0 MPa), the brake specific fuel consumption was 228 g/kWh. At full engine load (IMEP = 1.2 MPa), the brake specific fuel consumption was 223 g/kWh. When the engine was running at the low load (IMEP = 0.32 MPa), using diesel fuel and additive blends, the brake specific fuel consumption was higher by 5% and 7% in comparison to the engine running on pure diesel fuel.

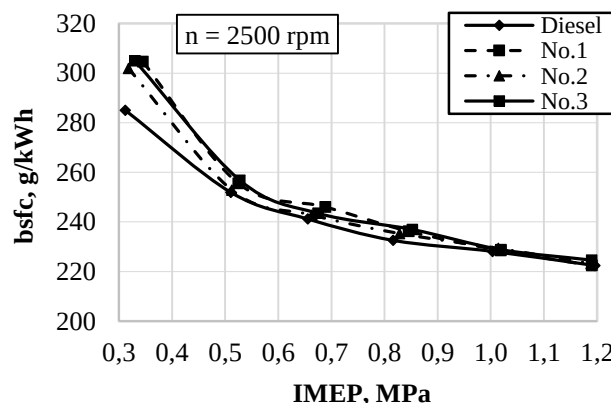


Fig. 4 The brake fuel consumption (bsfc) as a function of engine load (IMEP) at 2500 rpm

After testing, it can be argued that the diesel fuel and additives blends were not affected on the average gas pressure in the cylinder at low and medium load at rotation speed of 1800 rpm. The higher changes in the average gas pressure in cylinder occurred when increasing load to IMEP = 1.12 MPa at crankshaft speed of 1800 rpm (Fig.5).

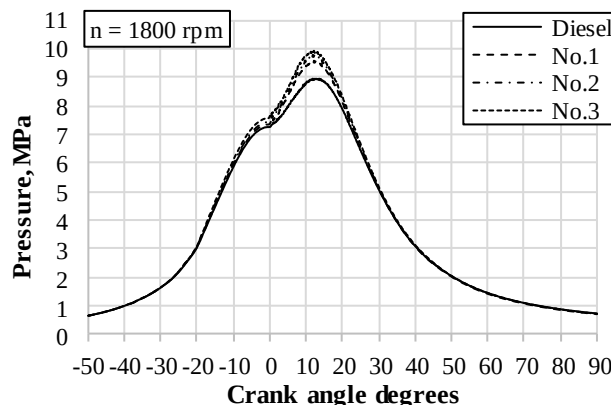


Fig. 5 The influence of fuel additives on cylinder pressure at IMEP = 1.12 MPa and 1800 rpm

The cylinder pressure is most pronounced using diesel fuel and additives blends when the engine is running at full load (1.12MPa) and speed of 1800 rpm (Fig. 2). At that point the maximum change in gas pressure inside the cylinder is observed. When the engine is running on normal diesel fuel, the maximum cylinder gas pressure is 8.89 MPa and with fuel additives blends it is 9.5, 9.8 and 9.87 MPa, respectively. Thus, a maximum 11% increase in pressure was obtained using additive No.3.

With the engine speed was 2500 rpm, fuel additives did not have any effect on the change of the average gas pressure in the cylinder. At both maximum and minimum loads, the gas pressure in the cylinder was changing with the same curve as when using pure diesel fuel.

There is no reason to expect big changes in brake specific fuel consumption or gas pressure. During the preparation of fuel blends, additives were mixed according to recommendations provided in

the instructions. During the preparation of mixtures, 62.5ml of additive No.1, 66.67ml of additive No.2, and 92.8ml of additive No.3 were injected into 20 litres of diesel fuel respectively. The additives in the 20-litre fuel mixture only accounted for 0.31, 0.33, and 0.46 % of volume. The factor, which had the greatest impact on the gas pressure in the cylinder and the brake specific fuel consumption, was the increasing load. When the load increases, the average gas pressure in the cylinder increases too, while the brake specific fuel consumption decreases evenly at higher power outputs. Stable engine operation was ensured by the computer of the CR fuel supply and control system.

The heat release rate was stable with engine running on both pure diesel fuel and of diesel fuel and additives blends. Since the test are carried out with a common rail fuel system, the curve reflects the heat release in the pre-injection and main injection stages. The maximum heat release rate during the pre-injection stage is 12.46 J/deg, when the piston has not yet reached to top dead centre (TDC) at 17.5 degrees of the rotation angle of the crankshaft. While the maximum heat release rate is 65.85 J/deg at 12 degrees past the TDC. These values were obtained with the crankshaft rotating speed of 1800 rpm at IMEP = 1.12 MPa.

The pre-injection fuel injection portion increases the average gas temperature to ~ 1400 K. This temperature was obtained both with the engine running on pure diesel fuel and diesel fuel with additives blends. After the main fuel injection stage, the average gas temperature in the cylinder has increased to the maximum of 2500 K degrees. During the tests, at lower loads or at higher 2500 rpm crankshaft revs, the average gas temperature was lower. Due to the lower load, the average gas temperature was lower both at 1800 and 2500 rpm, respectively. The higher average gas temperature at the same load was obtained at lower 1800 rpm crankshaft revs. This could have been caused by lower engine speed and a longer time span of the gas being in the cylinder.

5. Conclusion

1. When the diesel fuel and additive No.1 blend was used in the engine running at the speed of 2500 rpm and low load, the emission of carbon monoxide increased by 35 % compared to normal diesel fuel.

2. The highest values emission from 537 to 1115 ppm of the unburned hydrocarbons, were measured when the engine running on diesel fuel and additives No.1 and No.2 blends at the low load and 2500 rpm speed, compared to diesel fuel case.

3. In case of running the engine on normal diesel fuel at low loads, the brake specific fuel consumption was lower by 5 % and 7 %, respectively.

4. When the engine was operated on diesel fuel and additive No.3 blend at the full load and speed of 1800 rpm, the gas pressure in cylinder increased by 11% compared to normal diesel fuel.

6. References

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