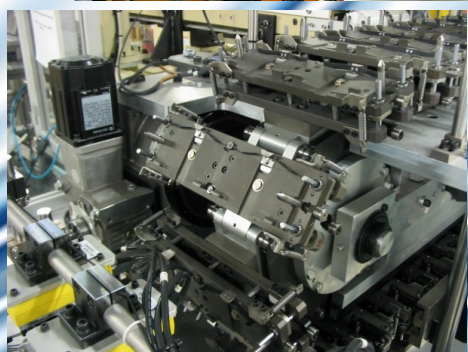


INTERNATIONAL SCIENTIFIC JOURNAL

YEAR I, ISSUE 4/2016, ISSN 2367-8399

# trans & MOTAUTO WORLD



SCIENTIFIC TECHNICAL UNION OF MECHANICAL ENGINEERING  
108 RAKOVSKI STR., SOFIA 1000, BULGARIA

**PUBLISHER:**

**SCIENTIFIC TECHNICAL UNION OF MECHANICAL ENGINEERING**

108, Rakovski Str., 1000 Sofia, Bulgaria

**tel.** (+359 2) 987 72 90,

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

[office@stumejournals.com](mailto:office@stumejournals.com)

**ISSN 2367-8399**

**YEAR I, ISSUE 4 / 2016**

## **EDITORIAL BOARD**

**CHIEF EDITOR**

**Prof. Petar Kolev, Bulgaria**

**RESPONSIBLE SECRETARY:**

Prof. Nikolay Tonchev, Bulgaria

### **MEMBERS:**

Prof. Ahmet H. Ertas, TR  
Prof. Aleksandar Kostikj, MK  
Prof. Andrey Ferenets, RU  
Prof. Angel Dimitrov, BG  
Prof. Beti Angelevska, MK  
Prof. Dainis Berjoza, LV  
Prof. Dan Scarpete, RO  
Prof. Daniela Todorova, BG  
Prof. Emilia Andreeva-Moschen, AT  
Prof. Gordana Marunic, HR  
Prof. Hristo Stanchev, BG  
Prof. Igor Penkov, EE  
Prof. Igor Smirnov, UA  
Prof. Iliyan Lilov, BG  
Prof. Lech Sitnik, PL  
Prof. Lilo Kunchev, BG

Prof. Ljudmila Boyko, UA  
Prof. Madaminjon Aripdzanov, UZ  
Prof. Martin Kendra, SK  
Prof. Massimo Borghi, IT  
Prof. Murat Dogruel, TR  
Prof. Natasa Tomic-Petrovic, RS  
Prof. Nikolay Georgiev, BG  
Prof. Oleg Sharkov, RU  
Prof. Pepo Yordanov, BG  
Prof. Polatbeg Zhunisbekov, KZ  
Prof. Rosen Ivanov, BG  
Prof. Teymuraz Kochadze, GE  
Prof. Tomaz Morchadze, GE  
Prof. Vadim Zhmud, RU  
Prof. Valyo Nikolov, BG  
Prof. Zoran Jovanovic, RS

# CONTENTS

|                                                                                                                                                                                                                                                                                       |    |
|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----|
| <b>IMPORTANCE OF TECHNICAL INSPECTION OF VEHICLES AFTER TRAFFIC ACCIDENTS</b><br>Assoc. Prof. Goran Zovak Head of Department., Tomislav Kučinić, Mag. Ing. Traff., Ivan Ševo, M.Sc. ....                                                                                              | 3  |
| <b>DESIGN FOR ACTIVE FLUTTER SUPPRESION AND MODEL VERIFICATION</b><br>Ing. Kratochvíl A., Bc. Svoboda F., Ing. Sommer T., Doc. Ing. Slavík S., CSc. ....                                                                                                                              | 7  |
| <b>WAYS OF EFFICIENCY'S INCREASING OF COMPUTER GRAPHICS PRODUCTION LIFE CYCLE PROCESSES.</b><br>Assoc. Prof. Dr. Econ. Abrahamyan V., MA Political Science, Ter-Sargsyan R. ....                                                                                                      | 11 |
| <b>DRIVER HEALTH AND TRAFFIC SAFETY ON THE TOURIST ROUTES</b><br>Assoc. Prof. Dr. Chogovadze J., Prof. Dr. Kochadze T., student Chogovadze L., student Kochadze A. ....                                                                                                               | 16 |
| <b>DESIGN AND ANALYSIS OF THE HYDRAULIC ARM FOR MOUNTING ON A LIGHT GOODS VEHICLE</b><br>Ing. Blatnický M. PhD., Ing. Dižo J. PhD., Assoc. prof. Ing. Dalibor Barta, PhD. ....                                                                                                        | 19 |
| <b>VEHICLE- AND STAFF PRODUCTIVITY IN BUS URBAN TRANSPORT</b><br>Ing. Vít Janoš, Ph.D., Ing. Milan Kříž .....                                                                                                                                                                         | 24 |
| <b>ADVANCED VISUALISATION TECHNOLOGIES AS A TOOL IN THE AREA OF AUTOMOTIVE ENGINEERING</b><br>Ass. Prof. Tashko Rizov PhD., Prof. Milan Kjosevski PhD., Prof. Risto Tashevski PhD. ....                                                                                               | 27 |
| <b>METHODOLOGY OF CARRYING RESEARCHES OF KINEMATIC PAIR OF PIVOTING FRICTION</b><br>Ph.D. Eng. Wozniak M., Ph.D. Eng.Kubiak P., Ph.D. Eng.Pluciennik P., M.Sc. Eng. Jozwiak P., Eng. Madziara S.,<br>Eng. Najbert S., Prof. M.Sc. Ozuna G., Eng. Gomez L., Ph.D. Eng. Chunbao L. .... | 32 |
| <b>THE NEW EXHAUST AFTERTREATMENT SYSTEM FOR REDUCING NOX EMISSIONS OF DIESEL ENGINES: LEAN NOX TRAP (LNT). A STUDY</b><br>PhD Student Eng. Vrabie V., Prof. Dr. Eng. Scarpete D., PhD Student Eng. Zbarcea O. ....                                                                   | 35 |
| <b>METHOD OF PROJECTS IN THEORY LEARNING OF A FUTURE AGRICULTURAL ENGINEER</b><br>Candidate of Technical Sciences, Associate Professor Viktor Pryshliak .....                                                                                                                         | 39 |

# IMPORTANCE OF TECHNICAL INSPECTION OF VEHICLES AFTER TRAFFIC ACCIDENTS

Assoc. Prof. Goran Zovak Head of Department,<sup>1</sup> Tomislav Kućinić, Mag. Ing. Traff.,<sup>2</sup> Ivan Ševo, M.Sc.<sup>3</sup>  
Faculty of Traffic and Transport Sciences<sup>1,2</sup> – University of Zagreb, Croatia

**Abstract:** The factors that affect on traffic safety are human, vehicle, road and environment. In Croatia the leading cause of traffic accident is human, in just 0,2% of traffic accident the cause is some technical defect on vehicle. However, analyzing the information that on the regular annual technical inspection more than 22% of the vehicle did not meet the technical requirements, to assume is that the number of defective vehicles that causes traffic accidents is significantly higher. In order to determine the relevant statistic data of vehicle as a cause of traffic accidents, it is necessary to implement technical inspection of vehicle that are involved in traffic accident. Research objectives are to determine how many defective vehicles were involved in traffic accident, how many of them might have been the cause of a traffic accident, and which elements on the vehicle are possible cause of traffic accident.

**Keywords:**

## 1. Introduction

According to the statistical data and analysis in the Republic of Croatia the leading cause of traffic accidents is human in over 97%, while in 0.2% of traffic accidents cause of the traffic accident was a technical breakdown. Analyzing the fact that in the European Union countries in 6-8% of traffic accidents the cause was a technical defect of the vehicle and in Croatia in about 22% the vehicles did not meet on a regular technical inspection, so it can be assumed that the cause of the larger number of traffic accidents was the technical malfunction of the vehicle. In order to achieve the target in the global campaign "Decade of action for road safety" it is necessary to determine the cause of traffic accidents.

The Republic of Croatia has not conducted research on the number of technically defective vehicles that are involved in traffic accidents so they used for example the exploration conducted by the company Dekra. The results of the research led by company Dekra, which since 2001 carried out an analysis of roadworthiness of all vehicles that are involved in traffic accidents with fatal consequences, showed that 26.4% of vehicles are out of order and 6% of investigated traffic accidents were caused by a technical malfunction of the vehicle. The Republic of Croatia has lower standard than Germany and inferior standard contributes to greater average age of registered vehicles in the Republic of Croatia, which in 2015 was 13.5 years. It can be concluded that the number of technically defective vehicles that are involved in traffic accidents increased and thus the technical malfunction as the cause of accidents is higher than 0.2%.

By determining the number of technically defective vehicles that are involved in traffic accidents the methodology of keeping statistics on the causes of traffic accidents improves, and quality measures for the prevention of traffic accidents can be applied.

In order to improve the statistics of the vehicle as a cause of road accidents, it is necessary to carry out technical inspections of vehicles that are involved in traffic accidents. Due to the large number of accidents it is necessary to carry out technical inspections on vehicles that are involved in traffic accidents with fatalities as consequences.

## 2. Technical inspection of vehicles after traffic accidents

### 2.1. The mandatory technical inspections of vehicles

In Croatia, all motor vehicles and trailers must access the final inspection. Vehicle Inspection is performed based on the Law on Road Traffic Safety, under the laws governing the operational part of the business, such as: Regulation on technical inspection of vehicles, Regulation on technical requirements for vehicles in road traffic, the Ordinance on the periodic technical inspection. The Act

defines devices and equipment which vehicles must contain, dimensions, total weight and axle load of vehicles and conditions to be met by vehicles in traffic on the roads. Table 1 shows the distribution of technical inspection in the Republic of Croatia.

**Table 1: Types of technical inspection**

| Regular checks                                                                      | Preventive checks                                                                                                                                                                                                                                                                                                                           | Exceptional technical inspection                                                                                                                                                                                                                                                                                                                                          |
|-------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Mandatory for                                                                       |                                                                                                                                                                                                                                                                                                                                             |                                                                                                                                                                                                                                                                                                                                                                           |
| <ul style="list-style-type: none"><li>• Motor vehicles</li><li>• Trailers</li></ul> | <ul style="list-style-type: none"><li>• renta a car vehicles</li><li>• vehicles for training drivers except the moped, motorcycle and tractor owned by candidates</li><li>• taxi vehicles</li><li>• buses</li><li>• duty vehicles (passenger cars and trailers) if their maximum mass exceeds 7500 kg</li><li>• ambulance vehicle</li></ul> | <ul style="list-style-type: none"><li>• all vehicles after repair of circuits and devices essential to traffic safety, which have been damaged in an accident</li><li>• vehicles that have carried out modifications or repairs</li><li>• vehicles that are excluded from traffic by authorized police officer and went to the exceptional technical inspection</li></ul> |
| exceptions                                                                          |                                                                                                                                                                                                                                                                                                                                             |                                                                                                                                                                                                                                                                                                                                                                           |
| <ul style="list-style-type: none"><li>• work machines</li></ul>                     | <ul style="list-style-type: none"><li>• camping and living vehicles</li><li>• vehicles for the transport of bees</li><li>• fire vehicles</li><li>• vehicles for leisure activities</li><li>• trailers for tractors</li></ul>                                                                                                                |                                                                                                                                                                                                                                                                                                                                                                           |

Vehicle Inspection is done in order to increase road safety. The laws and regulations on the provision of technical review can be found in the Law on Road Traffic Safety.

Basic tenets of technical inspection are:

1. Technical inspection of vehicles is an activity of general interest.
2. In order to test roadworthiness for motor vehicles and trailers, with the exception of machines, technical inspections of these vehicles are carried out.
3. Technical inspections of vehicles are regular with testing of exhaust gases of motor vehicles, preventive and exceptional.

4. On the technical inspection shall be determined whether the vehicle has prescribed devices and equipment, whether these devices and equipment are correct and whether they meet the prescribed conditions for participation in road traffic.
5. Record of technical inspection of vehicles shall be kept.
6. Minister of the Interior in agreement with the minister in charge for transport issues carries out regulations on the technical inspection of vehicles.

During technical inspection of the vehicle it is divided into 17 circuits that are reviewed. Table 2 shows the proportion of errors to the circuits on a regular technical inspection in 2015 for all categories of vehicles.

**Table 2: The percentage of defects in individual assemblies of vehicles [ 2 ]**

|    | Name of the assembly                                 | % defects |
|----|------------------------------------------------------|-----------|
| 00 | Identification of the vehicle                        | 1,03      |
| 01 | Control devices                                      | 2,86      |
| 02 | Braking devices                                      | 26,10     |
| 03 | Apparatus for lighting and light signals             | 26,67     |
| 04 | Devices that allow normal visibility                 | 3,53      |
| 05 | Self-supporting body, chassis and other parts        | 4,06      |
| 06 | Axles, wheels, tires and suspension                  | 10,52     |
| 07 | Engine                                               | 5,13      |
| 08 | The impact on the environment                        | 0,61      |
| 09 | Electrical equipment and installations               | 1,27      |
| 10 | Transmission mechanism                               | 1,24      |
| 11 | Control and signaling devices                        | 2,91      |
| 12 | Testing of exhaust gas                               | 8,46      |
| 13 | Connecting the towing and towed vehicles             | 0,76      |
| 14 | Other devices and vehicle parts                      | 0,44      |
| 15 | Vehicle equipment                                    | 4,08      |
| 16 | Additional testing of vehicles of category M2 and M3 | 0,01      |
| 17 | Gas installations                                    | 0,31      |

The highest percentage of failure on regular technical inspections have devices for lighting and light with 26.67% defect, then the braking device with 26.10%, and the circuit elements of axles, wheels, tires and suspension with 10.52% then testing of emissions. Vehicles must meet all conditions. All circuits on the vehicle must be correct or individual circuits directly affect traffic safety. Some circuits from the standpoint of security are more important than other circuits. Testing of exhaust gases of motor vehicles are more significant for ecology but the devices for lighting and light-signaling devices for braking, steering devices and components axles, wheels, tires and suspension are more important for road safety and their malfunction is affecting the safety of road traffic.

Age of vehicles is one of the factors that influence the malfunction of the vehicle. The infrastructure enables drivers of older vehicles movement in high speeds and significantly increases the possibility of accidents with serious consequences. Table 3 shows the analysis of the failure of passenger cars by manufacturers, who have access to regular technical inspection

under 5 years of age, between 5 and 10 years of age and older than 10 years.

**Table 3: The percentage of malfunctions of cars under 5 years of age, between 5 years and 10 years and over 10 y. [2]**

| Under 5 years |                | Between 5 and 10 years |                | Over 10 years |                |
|---------------|----------------|------------------------|----------------|---------------|----------------|
| Vehicle       | % malfunctions | Vehicle                | % malfunctions | Vehicle       | % malfunctions |
| Audi          | 2,99           | Audi                   | 7,39           | Toyota        | 20,05          |
| Mazda         | 2,99           | Bmw                    | 7,46           | Smart         | 20,26          |
| Volkswagen    | 3,65           | Volvo                  | 8,83           | Mercedes      | 25,03          |
| Ford          | 3,90           | Honda                  | 9,21           | Mazda         | 25,59          |
| Suzuki        | 4,33           | Suzuki                 | 9,67           | Bmw           | 25,65          |
| Bmw           | 4,59           | Mazda                  | 9,78           | Volvo         | 26,07          |
| Nissan        | 4,59           | Mercedes               | 9,94           | Nissan        | 27,52          |
| Mercedes      | 4,62           | Volkswagen             | 11,50          | Mitsubishi    | 28,53          |
| Seat          | 4,68           | Nissan                 | 11,94          | Honda         | 28,70          |
| Toyota        | 4,72           | Toyota                 | 12,02          | Citroen       | 28,70          |
| Opel          | 4,95           | Ford                   | 12,84          | Peugeot       | 28,94          |
| Škoda         | 5,13           | Hyundai                | 13,78          | Audi          | 28,94          |
| Renault       | 5,27           | Kia                    | 14,46          | Hyundai       | 29,12          |
| Kia           | 5,33           | Opel                   | 14,80          | Lancia        | 30,40          |
| Hyundai       | 5,73           | Renault                | 15,29          | Renault       | 30,88          |
| Dacia         | 6,16           | Alfa romeo             | 15,94          | Alfa romeo    | 31,06          |
| Peugeot       | 6,21           | Peugeot                | 16,25          | Škoda         | 31,38          |
| Citroen       | 6,83           | Citroen                | 16,25          | Seat          | 32,08          |
| Chevrolet     | 7,98           | Seat                   | 16,57          | Opel          | 32,34          |
| Fiat          | 9,74           | Škoda                  | 16,99          | Volkswagen    | 33,68          |
|               |                | Chevrolet              | 17,03          | Daewoo        | 33,89          |
|               |                | Fiat                   | 17,44          | Suzuki        | 35,42          |
|               |                | Dacia                  | 18,74          | Ford          | 35,50          |
|               |                |                        |                | Fiat          | 36,46          |
|               |                |                        |                | Rover         | 37,09          |
|               |                |                        |                | Kia           | 37,84          |
|               |                |                        |                | Lada          | 42,20          |
|               |                |                        |                | Zastava       | 48,17          |

An examination of Table 3 confirms that the age of the vehicle is an important factor in road safety. Vehicles up to 5 years of age have a percentage of malfunction 2.99 to 9.74%, vehicles 5-10 years of age have a failure rate from 7.39 to 18.74% and the vehicles that are older than 10 years have a 20 percent failure , from 05 to 48.17%. With the age of the vehicle an important factor is mileage. For vehicles that have passed less than 50 000 km percentage of defects is from 4.01 to 24.75%, with vehicles that

have crossed 50000-100000 percentage of defects is from 5.69 to 26.73% for vehicles with more 100 000 mileage percentage of defects is 16.32 to 38.10%. In addition to the data presented, the devastating fact is that in 2014 and 2015 in Croatia higher number of used vehicles approached the first regular technical than new vehicles as a result of large imports of vehicles.

## 2.2. Technical inspection of vehicles after traffic accidents

Vehicles that were involved in traffic accidents are not accessing technical inspection unless technical malfunction is suspected or if requested by the prosecution. Technical inspection of vehicles after a car accident is different compared to the regular technical inspection station. When checking the technical condition of vehicles that are involved in traffic accidents it is allowed to dismantle and assemble circuit boards to determine a malfunction. In order to implement the project *"Check the technical condition of vehicles involved in traffic accidents with fatalities"* the methodology of the technical inspection of vehicles as part of the designed pattern to check the correctness of assembly of vehicles that meet the supervisor during the review was formed. The above pattern is different from the control list in the roadworthiness test, inspection form safety circuits of vehicles consists of 4 pages, which are divided into six main circuits. After vehicle inspection data on the inspection are entered to the application along with photos and other attachments. Technical inspection of vehicles that are involved in a car accident may take longer than vehicle inspection during regular technical inspection..

Example of analysis of the vehicle that was involved in an accident with fatal consequences. Inspection of the vehicles performed outside the station for technical inspection. Inspecting the cargo delivery vehicle brand and type Volkswagen Transporter. Technical inspection starts by entering data on the vehicle and on the person performing the inspection. The form of vehicle inspection is divided into six segments and should be completely fulfilled, to be completed in a way that the individual assembly can be characterized as:

- Properly
- Malfunctioning
- It is not possible to determine the condition before the accident
- Activated (valid for airbags and seat belts)
- The set does not exist

At present vehicle, there were a number of malfunctions of which only some are listed:

- The windshield was damaged, and a mesh rupture passes through the driver's field
- The body is corroded and especially thresholds of the vehicles which weakened structure of the vehicle
- The seat is damaged and as such violates the comfort of the driver visible in the photograph
- In the interior of the vehicle there are sharp parts that could cause injury to the driver and missing safety barrier between the passenger and cargo space, which prevents the entry of cargo into the passenger compartment. Missing interior mirror which originally was improperly secured with chewing gum (Fig. 1)
- Position and high beams do not work
- Drive elements of additional devices are not functioning. Drive belt that drives the hydraulic pump or the steering is missing and even if the belt is correct this is considered defective because the hydraulic control device is subsequently improperly installed (Fig. 1)

- Evaporation temperature of brake fluid is invalid because the humidity is above 4%.
- The parking brake is not in function
- Tires are worn on the outer part of the tread pattern which indicates an incorrect suspension geometry
- Sidewall tires are damaged, cracked or damaged (Fig. 1)
- Some tires are renewed, and the tread in places began to peel off

A technical inspection has determined that the subject vehicle was defective and as such should not participate in road traffic. A large number of defects was observed on circuits that are important for road safety. Since they do not know the details of an accident it cannot be determined whether it is a technical malfunction of the vehicle causing a traffic accident or some other factor. Defects that were observed on the vehicle in certain situations may be the cause of an accident since the faulty circuits are of active safety.

For vehicles where the percentage of moisture in the brake fluid is higher than 4% and have worn or damaged tires there is a possibility that their braking distance extended in relation to the technically correct vehicle. Visibility of drivers can be reduced if the internal mirror is missing, if he damaged the front windshield even if the light units are not correct. The duration of the review of the vehicles was about one hour and thirty minutes.

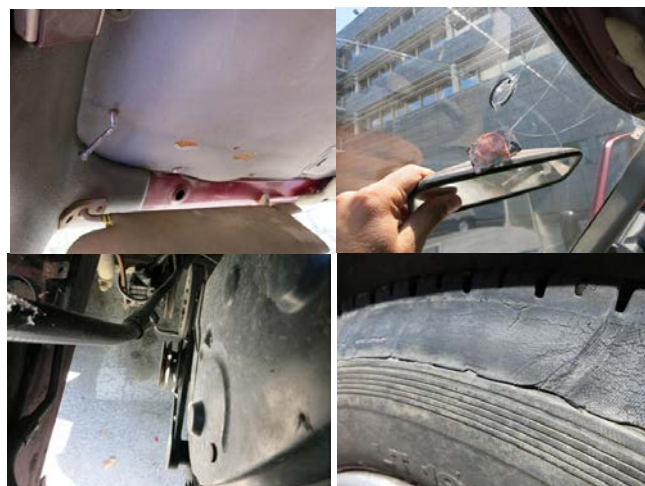


Fig. 1. Examples of some technical defect in the subject vehicle [3]

Information recorded during the technical inspection of vehicles shall be entered in the application created just for the purpose of technical inspection of vehicles that are involved in traffic accidents with fatal consequences [1].

### 2.2.1. Problems during technical inspection of vehicles after traffic accidents

Technical inspection of vehicles that took part in a car accident is more difficult to perform than a full technical review of the roadworthiness test. Vehicles that are involved in traffic accidents are usually deformed and it is impossible to technically determine in a safe way whether a malfunction occurred before the car accident or the result of a traffic accident. Vehicles are usually reviewed in parking lots or other areas where all workshop equipment is not available, making it difficult to monitor vehicle inspection. The vehicles in which someone is killed can be found traces of blood, and this can cause discomfort to the individual supervisor. When inspecting the damaged vehicle it requires maximum caution because the vehicle is deformed but has sharp edges on which the supervisor can hurt himself. In some cases it is necessary to repair the vehicle in order to examine the individual circuits.

Inspection of the vehicles that were involved in traffic accidents take place in the shortest possible time after the car accident because the atmospheric conditions can modify individual circuits that make it difficult for the monitor to review.

Inspections of vehicles that are involved in traffic accidents are reviewed throughout the Republic of Croatia and need a large number of available professional staff who can inspect the vehicle in any part of the country.

### **3. Implement technical inspection of vehicle that are involve in traffic accident with fatal consequences**

To determine the number of defective vehicles that are involved in traffic accidents with fatal consequences it is necessary when an accident with fatal consequences occurs to retain vehicles temporarily in the local police station. Vehicles that are involved in these traffic accidents must be disposed of in a secure area to protect vehicles from the potential impact of weather conditions. It is necessary to allow the access to the vehicles that are involved in traffic accidents only to authorized institutions and professional staff who would be responsible for reviewing the technical condition of vehicles.

It is necessary to form a professional staff that is able to inspect the vehicle in any part of Croatia. To perform the necessary inspection, equipment is needed in order to review the damaged vehicle without certain specialized workshops. If the vehicle after a traffic accident in running the supervisor is allowed to transport the vehicle and inspect the roadworthiness. In addition to these procedures it is necessary to prepare regulations so that during the examination of vehicles of recent production it is allowed to read data from the EDR (event data recorder) which when the airbag is triggered captures certain information that can be used to determine the causes of traffic accidents. The information collected during the inspection of the vehicle can be used by traffic experts if they are making finding and opinion of an accident in which the participants examined the vehicle.

The former performed examinations of vehicles as part of the "Technical examination of vehicles involved in traffic accidents with fatalities" on vehicles which are technically incorrect, it was found that 27.93% had a malfunction on tires and suspension which are active safety factors as these are an important element of security. Table 4 shows the percentages of defects per circuits identified with defective vehicles.

**Table 4: malfunctioning of the circuits identified with defective vehicles[1]**

| Set                       | % vehicles |
|---------------------------|------------|
| Body and interior cabin   | 30,02      |
| The suspension and tires  | 27,93      |
| Engine and transmission   | 15,41      |
| Braking system            | 11,91      |
| Light signaling equipment | 10,51      |
| Driving system            | 4,22       |

Table 4 shows that 54.57% defects found are on circuits that are most important for road safety. Malfunction of any circuit on the vehicle endanger participants in traffic and especially malfunction of active safety factors on which the highest number of irregularities are recorded.

## **4. Results**

With the introduction of the technical inspection of vehicles participating in road accidents with fatal consequences the current statistics on the number of defective vehicles that are involved in traffic accidents with fatal consequences would improve. By analyzing traffic accident data and the technical condition/ breakdown methodology of collecting data on the cause of an accident would be advanced and changed. Improving statistics on the causes of accidents high-quality measures can be aimed at reducing the number of deaths of participants of traffic.

By determining to what extent a technical malfunction caused a traffic accident, preventive measures can be taken to encourage public awareness about the fatal consequences of the exploitation of technically defective vehicles, because for a large number of defects user of the vehicle is responsible. By raising awareness of the fatal consequences of the exploitation of technically defective vehicles, awareness of vehicle owners about the importance of regular maintenance and control of the vehicle would increase. Pointing drivers to the fact that increased vehicle age and mileage is increasing the possibility of technical failure, and therefore the traffic safety of all participants is violated, and thus the trend of a large number of first time registered used vehicles than new ones could change.

## **5. Conclusion**

By achieving the set target set by the global campaign "Decade of action for road safety" , to reduce the number of casualties in road transport by 50% by 2020 is achievable if all causes of traffic accidents are determined in order to impose preventive measures in order to achieve a given objective.

Actions and methodology of inspections of damaged vehicles is more demanding than the inspection of vehicles that approach the regular technical roadworthiness test. In some cases, vehicles are deformed and the supervisor finds it difficult to ascertain the correctness of circuits before a traffic accident. Vehicles should be inspected immediately by the supervisor after a traffic accident and damaged vehicles should be placed in a guarded area to undergo the examination.

To determine the number of technically defective vehicles involved in road transport it is necessary to implement outstanding technical checks on roads by excluding the vehicle out of traffic and performing inspections.

In order to achieve the objective of 50% fewer casualties in road transport by the technical inspection of vehicles that are involved in traffic accidents it is necessary to form a professional staff that is responsible for infrastructure and human behavior. In Croatia, road safety will increase by the application of those measures and by an increase in living standards when citizens will be able to afford new vehicles.

## **6. References**

1. Zovak, G., Nacionalni program sigurnosti cestovnog prometa Republike Hrvatske, "Provjera tehničke ispravnosti vozila koja sudjeluju u prometnim nesrećama sa smrtno stradalim osobama"
2. Kalauz, Z. (2007)., *Tijek tehničkog pregleda*, Stručni bilten broj 119, Centar za vozila Hrvatske, Zagreb
3. Kučinić, T. (2014). *Značajke tehničkog pregleda nakon prometne nesreće*, Diplomski rad, Fakultet prometnih znanosti, Zagreb

## DESIGN FOR ACTIVE FLUTTER SUPPRESSION AND MODEL VERIFICATION

Ing. Kratochvíl A.<sup>1</sup>, Bc. Svoboda F.<sup>2</sup>, Ing. Sommer T.<sup>1</sup>, Doc. Ing. Slavík S., CSc.<sup>1</sup>,  
Faculty of Mechanical Engineering – Czech Technical University in Prague, the Czech Republic<sup>1</sup>  
Faculty of Electrical Engineering – Czech Technical University in Prague, the Czech Republic<sup>2</sup>  
ales.kratochvil@fs.cvut.cz

**Abstract:** The article deals with developing a mathematical model of non-rigid aircraft lifting surface with control surface controlled by pilot and supplementary control surface driven by control law. The purpose of this model is to determine if such as concept of control surface and supplementary control surface can be used for active flutter suppression on an aircraft structure. The supplementary control surface is placed next to the control surface at outboard side. The lifting surface is representing by an airfoil placed at 70% of a wing span.

*A structural model is developed by means of Lagrange differential equations of second kind. Theodorsen model of thin oscillation airfoil with control surface is used for unsteady aerodynamic. Duhamel's integral of Wagner function is carried out for transformation of unsteady aerodynamic to a time domain. The mathematical model is present in state space representation. There is exemplification of the critical flutter velocity calculation and a dynamical response of the structure. The supplementary control surface for flutter suppression with simplified model is added. Closed-loop feedback control system is formed and a several control laws are presents. The verification of open-loop model is done on behalf of the critical flutter speed comparison with FEM software for flutter analysis MSC.Nastran and flutter analysis program developed at CTU in Prague. The article also presents work on an experimental verification of the open-loop model in aerodynamic tunnel.*

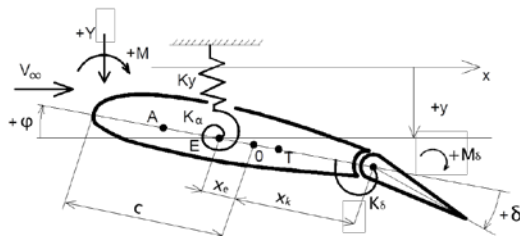
**Keywords:** FLUTTER, ACTIVE SUPPRESSION, STATE SPACE REPRESENTATION, NASTRAN,

## 1. Introduction

Flutter is self-excited oscillation of aircraft structure which leads to complete destruction of an aircraft. It is defined by so called flutter velocity. Above this velocity a damping is positive so amplitude of oscillation increases within the time. Each type of aircraft has to prove that is flutter free up to 1.2\*Design Velocity of an airplane, before a serial production start. There are several ways how to move the flutter to higher velocity. The most common way is by mass balancing or by aerodynamic balancing of control surface. There are also some other ways [1]. A research in area of increasing the flutter velocity of an aircraft structure is aimed at active suppression by a control surface to damp an oscillation above the flutter velocity [2] [3]. This paper is aimed to verify a new approach of flutter suppression. This approach lies in splitting the control surface in two parts. The inboard part of control surface remains as usual controlled by pilot to maneuver with aircraft. The outboard part of control surface will be driven by control law to suppress undamped oscillation of an airfoil.

## 2. Structural model

The structural model of the airfoil was developed on behalf of Lagrange differential equations of second kind (LDE.II) for three degree of freedom in plunge, pitch and control surface rotation see the model at figure 1. An opposite orientation of coordination system is given by used aerodynamic model.



**Fig. 1** Model of the airfoil.

We obtain three differential equation of second order by applying LDE.II. In matrix form written as

$$(1) \quad [M_s]\{\ddot{q}\} + [T_s]\{\dot{q}\} + [K_s]\{q\} = \{F_A\}$$

where  $M_s$  - structural mass matrix,  $T_s$  - structural damping matrix,  $K_s$  - structural stiffness matrix,  $F_A$  - vector of unsteady aerodynamic forces and  $q$  - deformation vector are defined as follow:

$$q = [y \quad \varphi \quad \delta]^T$$

$$[M_S] = \begin{bmatrix} m & S_{EO} & S_\delta \\ S & J & (x_K - x_E)S_\delta + J_\delta \\ S_\delta & (x_K - x_E)S_\delta + J_\delta & J_\delta \end{bmatrix},$$

$$[T_S] = \begin{bmatrix} b_y & 0 & 0 \\ 0 & b_\varphi & 0 \\ 0 & 0 & b_\delta \end{bmatrix}, [K_S] = \begin{bmatrix} K_y & 0 & 0 \\ 0 & K_\varphi & 0 \\ 0 & 0 & K_\delta \end{bmatrix}, \{F_A\} = \begin{bmatrix} Y \\ M \\ M_\delta \end{bmatrix}$$

where  $m$  – is mass,  $S$  – static moment,  $J$  – moment of inertia,  $x_k$  – hinge axis,  $x_e$  – elastic axis,  $b$  – viscous damping,  $K$  – stiffness,  $y$  – plunge,  $\varphi$  – pitch,  $\delta$  – control surface rotation,  $Y$  – lift,  $M$  – aerodynamic moment,  $M_\delta$  – hinge moment. Because this study is aimed on airfoil investigation without influence of wing span the units of mass matrix and aerodynamic vector are specific.

### 3. *Unsteady aerodynamic*

The mathematical model of airfoil unsteady aerodynamic forces is based on Theodorsen thin harmonically oscillation airfoil [4]. This model is commonly used for flutter analysis because consider not only aerodynamic forces as a function of free stream velocity but also take in account a change of lift and moment due to airfoil plunge, pitch and control surface rotation.

$$(2) \quad Y = -\rho c^2 \left[ v \pi \dot{\phi} + \pi \dot{y} - \pi c \tilde{x}_e \ddot{\phi} - v T_4 \dot{\delta} - T_1 c \ddot{\phi} \right] - 2\pi \rho v c C_{(k)} \left[ v \phi + \dot{y} + c \left( \frac{1}{2} \tilde{x}_e \right) \dot{\phi} + \frac{T_{10}}{\pi} v \delta + \frac{c T_{11}}{2\pi} \dot{\delta} \right]$$

$$(3) \quad M = -\rho c^2 \left[ \pi \left( \frac{1}{2} - \bar{x}_e \right) v c \dot{\phi} + \pi c^2 \left( \frac{1}{8} + \bar{x}_e^2 \right) \ddot{\phi} + (T_4 + T_{10}) v^2 \delta + (T_1 - T_8 - (\bar{x}_k - \bar{x}_e) T_4 + \frac{T_{11}}{2}) c \dot{\delta} - (T_7 + (\bar{x}_k - \bar{x}_e) T_1) c^2 \ddot{\delta} - \bar{x}_e \pi c \dot{y} \right] + 2\rho v c^2 \pi \left( \bar{x}_e + \frac{1}{2} \right) \mathcal{C}_{(k)} [v\varphi + \dot{y} + c \left( \frac{1}{2} - \bar{x}_e \right) \dot{\phi} + \frac{T_{10}}{\pi} v \delta + \frac{c T_{11} \dot{\delta}}{2\pi}]$$

$$(4) \quad M_\delta = -\rho c^2 \left[ \left( -2T_9 - T_1 + T_4 \left( \tilde{x}_e - \frac{1}{2} \right) \right) \text{vc}\dot{\varphi} + 2T_{13}c^2\dot{\varphi} + \frac{v^2}{\pi}(T_5 - T_4T_{10})\delta - \frac{\text{vc}}{2\pi}T_4T_{11}\dot{\delta} - \frac{T_{13}c^2}{2\pi}\ddot{\delta} - T_1c\ddot{y} \right] - \rho \text{vc}^2 T_{12}C_{(k)} \left[ v\varphi + \dot{y} + c \left( \frac{1}{2} - \tilde{x}_e \right) \dot{\varphi} + \frac{T_{10}}{2\pi}v\delta + \frac{cT_{11}\dot{\delta}}{2\pi} \right]$$

where  $\rho$  – density,  $c$  – semichord,  $v$  – air stream velocity,  $T_{1\pm 1}$  – Theodorsen constant,  $C_{(k)}$  – Theodorsen function. The first group of terms of equations (2) ÷ (4) are called non-circulatory or apparent mass component and they account for inertia of the fluid. The second groups of terms characterized by Theodorsen function  $C(k)$  are called circulatory components and they take in account an influence of the shed wake vorticity. Thus the vector of unsteady aerodynamic forces can be written as

$$(5) \quad \{F_a\} = \begin{Bmatrix} Y^{NC} \\ M^{NC} \\ M_\delta^{NC} \end{Bmatrix} + \begin{Bmatrix} Y^C \\ M^C \\ M_\delta^C \end{Bmatrix} = \{F_a^{NC}\} + \{F_a^C\}$$

where  $F_a^{NC}$  - non-circulatory part of aerodynamic load can be written in form of aerodynamic matrix of mass, damping and stiffness respectively as follow

$$(6) \quad \{F_a^{NC}\} = [M_A]\{\ddot{q}\} + [T_A]\{\dot{q}\} + [K_A]\{q\}$$

The  $F_a^C$  - circulatory part of aerodynamic load is

$$(7) \quad \{F_a^C\} = \begin{bmatrix} -2\pi\rho v^2 c \\ 2\pi\rho v^2 c^2(\tilde{x}_e + \frac{1}{2}) \\ -\rho v^2 c^2 T_{12} \end{bmatrix} C_{(k)} Q_{(t)}$$

Where  $Q_{(t)}$  - is deformation vector defined as

$$(8) \quad Q_{(t)} = v\varphi + \dot{y} + c(\frac{1}{2}\tilde{x}_e)\dot{\varphi} + \frac{T_{10}}{\pi}v\delta + \frac{cT_{11}}{2\pi}\delta$$

The term  $C_{(k)}$  of equation (7) is in frequency domain and term  $Q_{(t)}$  is in time domain. Thus the term  $C_{(k)}$  has to be transferred to time domain for purpose of state space model. This can be done on behalf of convolution by means of Duhamel's integral. The Theodorsen and Wagner function are related by mean of Fourier transformation pairs  $\psi_{(t)} = C_{(k)}$  so the Duhamel's integral can be written as

$$(9) \quad \{F_a^C\} = \begin{bmatrix} -2\pi\rho v^2 c \\ 2\pi\rho v^2 c^2(\tilde{x}_e + \frac{1}{2}) \\ -\rho v^2 c^2 T_{12} \end{bmatrix} \left[ Q_{(t=0)}\psi_{(t)} + \int_0^t \frac{\partial Q_{(t)}}{\partial \tau} \psi_{(t-\tau)} d\tau \right]$$

An explicit expression for the Wagner function does not exist so for practical evaluation of Duhamel's integral of Wagner function a subsonic approximation by second order exponentials function is used given by [5]

$$(10) \quad \psi_{(t)} \doteq \Phi_{(t)} = 1 - \alpha_1 e^{(-\beta_1 v t/c)} - \alpha_2 e^{(-\beta_2 v t/c)}$$

$$\alpha_1 = 0.2048 \quad \alpha_2 = 0.2952 \quad \beta_1 = 0.0557 \quad \beta_2 = 0.3330$$

Thanks this approximation the solutions of the Duhamel's integral can be written in state space form as [6]:

$$(11) \quad \begin{bmatrix} \dot{l}_1 \\ \dot{l}_2 \end{bmatrix} = \begin{bmatrix} 0 & 1 \\ -\beta_1\beta_2(\frac{v}{c})^2 & -(\beta_1 + \beta_2)(\frac{v}{c}) \end{bmatrix} \begin{bmatrix} l_1 \\ l_2 \end{bmatrix} + \begin{bmatrix} 0 \\ 1 \end{bmatrix} Q_{(t)}$$

$$(12) \quad y_{(t)} = \left[ \left( \frac{\beta_1\beta_2}{2} \right) \left( \frac{v}{c} \right)^2 \quad (\alpha_1\beta_1 + \alpha_2\beta_2) \left( \frac{v}{c} \right) \right] \begin{bmatrix} l_1 \\ l_2 \end{bmatrix} + \frac{1}{2} Q_{(t)}$$

or

$$(13) \quad \{l\} = [A_2]\{l\} + [B_2]\{u_2\}$$

$$(14) \quad \{y_2\} = [C_2]\{l\} + [D_2]\{u_2\}$$

Where  $l_1, l_2$  - are an aerodynamic lag states, A - system matrix, B - input matrix, C - output matrix, D - noise matrix, u - input.

#### 4. Open-loop model

The open-loop model also called as a system is formed in state space representation by merging the structural model with non-circulatory part of aerodynamic load including a positive feedback formed by circulatory part of aerodynamic loads. The output of the model has to be in form of position, velocity and acceleration for all degree of freedom, for purpose of control law. A schema for model of System is presented at Figure 2.

The structural and aerodynamic model is given as follow:

$$(15) \quad [M_s]\{\ddot{q}\} + [T_s]\{\dot{q}\} + [K_s]\{q\} =$$

$$= [M_A]\{\ddot{q}\} + [T_A]\{\dot{q}\} + [K_A]\{q\} + \{F_a^C\}$$

by transformation to state space representation we obtain

$$(16) \quad \begin{bmatrix} \dot{x}_1 \\ \dot{x}_2 \end{bmatrix} = \begin{bmatrix} 0 & 1 \\ [M]^{-1}[K] & [M]^{-1}[T] \end{bmatrix} \begin{bmatrix} x_1 \\ x_2 \end{bmatrix} + \begin{bmatrix} 0 \\ [M]^{-1} \end{bmatrix} \{F_a^C\}$$

$$(17) \quad y_1 = \begin{bmatrix} I & 0 \\ 0 & I \end{bmatrix} \begin{bmatrix} x_1 \\ x_2 \end{bmatrix} + \begin{bmatrix} 0 \\ 0 \\ [M]^{-1} \end{bmatrix} \{F_a^C\}$$

or

$$(18) \quad \{\dot{x}\} = [A_1]\{x\} + [B_1]\{u_1\}$$

$$(19) \quad \{y_1\} = [C_1]\{x\} + [D_1]\{u_1\}$$

where  $M = M_s - M_A, T = T_s - T_A, K = K_s - K_A, x_1 = q, x_2 = \dot{q}$ ,

The circulatory part of aerodynamic load  $\{F_a^C\}$  is formed by Duhamel's integral multiple by matrix of aerodynamic constant

$$(20) \quad [K_3] = \begin{bmatrix} -2\pi\rho v^2 c \\ 2\pi\rho v^2 c^2(\tilde{x}_e + \frac{1}{2}) \\ -\rho v^2 c^2 T_{12} \end{bmatrix}$$

The input to Duhamel's integral represent by Eq. (13) and (14), has to be cut of about second derivation of DOF because they are not needed here. So the following reduction matrix is added in front of Duhamel's integral:

$$(21) \quad [K_Z] = \begin{bmatrix} I & 0 & 0 \\ 0 & I & 0 \end{bmatrix}$$

We can obtain the open loop model of system by merging equations (13), (14), (18), (19), (20), (21) according the schema on figure 2. Then the state space representation of system is

$$(22) \quad \{\dot{x}_{sys}\} = \begin{bmatrix} A_1 + B_1 K_3 D_2 K_Z C_1 & B_1 K_3 C_2 \\ B_2 K_Z C_1 & A_1 \end{bmatrix} \{x_{sys}\} + \begin{bmatrix} B_1 \\ 0 \end{bmatrix} \{u_{sys}\}$$

$$(23) \quad \{y_{sys}\} = [C_1 \quad 0]\{x_{sys}\} + [D_1]\{u_{sys}\}$$

or

$$(24) \quad \{\dot{x}_{sys}\} = [A_{sys}]\{x_{sys}\} + [B_{sys}]\{u_{sys}\}$$

$$(25) \quad \{y_{sys}\} = [C_{sys}]\{x_{sys}\} + [D_{sys}]\{u_{sys}\}$$

with state vector  $\{x_{sys}\} = \{x \ l\}^T = \{y \ \varphi \ \delta \ \dot{y} \ \dot{\varphi} \ \dot{\delta} \ l_1 \ l_2\}^T$

input vector  $\{u_{sys}\} = \{0 \ 0 \ 0\}^T$

and output vector  $\{y_{sys}\} = \{y \ \varphi \ \delta \ \dot{y} \ \dot{\varphi} \ \dot{\delta} \ \ddot{y} \ \ddot{\varphi} \ \ddot{\delta}\}^T$ .

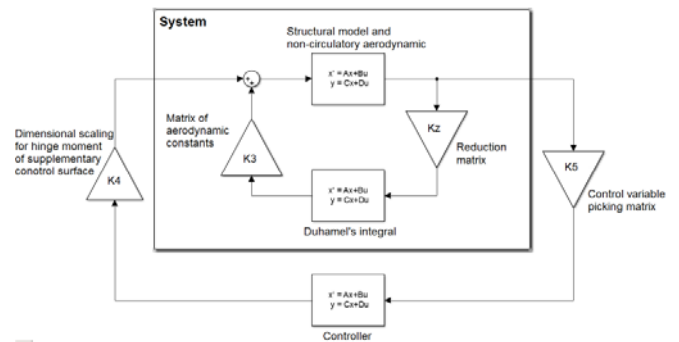


Fig. 2 Schema of the closed-loop model

#### 5. Closed-loop model

There was added the supplementary control surface with controller to the feedback loop of the system. The purpose is an active damping of an airfoil oscillation and shifting the flutter velocity to higher speeds. The supplementary control surface is intangible and non-rigid with aerodynamic load generated on behalf of supplementary control surface rotation  $\Theta$  only. The transport delays, servo transfer function or sensor noise is not taken in account. This paper is focused on testing if a possibility of the new concept of flutter suppression is possible at all. The supplementary control surface hinge moment  $M_\theta$  is defined as

$$(26) \quad M_{\Theta} = \frac{1}{2} \rho v_{\infty}^2 \bar{b}_k c_y^{\Theta} (\bar{x}_k - \bar{x}_e) c^2 \Theta$$

$$\text{where } \bar{b}_k = \frac{b_k}{2c}, \quad c_y^{\Theta} = 2 \left( a \cos(1 - 2\bar{b}_k) + 2\bar{b}_k(1 - 2\bar{b}_k) \right)$$

and will extend equation (5) as follow

$$(27) \quad \{F_a\} = \begin{Bmatrix} Y^{NC} \\ M^{NC} \\ M_{\delta}^{NC} + M_{\Theta} \end{Bmatrix} + \begin{Bmatrix} Y^C \\ M^C \\ M_{\delta}^C \end{Bmatrix}$$

The angle of rotation  $\Theta$  will be driven by controller on behalf of the control variable chosen from system output  $y_{sys}$ . There has to be considered another two gain matrix and state space model for regulator to form the closed loop model. The first matrix is for picking a control variable on behalf of system output

$$(28) \quad [K_5] = [R_1 \ R_2 \ R_3 \ R_4 \ R_5 \ R_6 \ R_7 \ R_8 \ R_9]$$

Where all constant  $R_i$  are zero except the one representing control variable which will be set  $\pm 1$  where positive or negative sing is for generating hinge moment in phase or antiphase according to control variable.

The controller transfer function is transform to state space model and added to closed-loop in flowing form

$$(29) \quad \{\dot{z}_R\} = [A_R]\{z_R\} + [B_R]\{u_R\}$$

$$(30) \quad \{y_R\} = [C_R]\{z_R\} + [D_R]\{u_R\}$$

with input as a control variable and output as a supplementary control surface rotation angle  $y_R = \Theta$ . The second gain matrix

$$(31) \quad [K_4] = \begin{bmatrix} 0 \\ 0 \\ \frac{1}{2} \rho v_{\infty}^2 \bar{b}_k c_y^{\Theta} (\bar{x}_k - \bar{x}_e) c^2 \end{bmatrix}$$

Generate the supplementary control surface hinge moment on behalf of rotation angle  $\Theta$ , given by controller. Then the closed-loop model given in figure 2 is defined as follow:

$$(32) \quad \{\dot{x}_{RS}\} = \begin{bmatrix} A_{sys} & B_{sys} K_4 C_R \\ B_R K_5 C_{sys} & A_R \end{bmatrix} \begin{Bmatrix} x_{sys} \\ z_R \end{Bmatrix} + [0] \{u_{RS}\}$$

or

$$(33) \quad \{\dot{x}_{RS}\} = [A_{RS}]\{x_{RS}\}$$

$$(34) \quad \{y_{RS}\} = \{y_{sys}\}$$

with state vector  $\{x_{RS}\} = \{y \ \varphi \ \delta \ \dot{y} \ \dot{\varphi} \ \dot{\delta} \ l_1 \ l_2 \ z_{R1} \ z_{R2}\}^T$

input vector  $\{u_{RS}\} = \{0 \ 0 \ 0\}^T$

and output vector  $\{y_{RS}\} = \{y \ \varphi \ \delta \ \dot{y} \ \dot{\varphi} \ \dot{\delta}\}^T$ .

## 6. Flutter velocity and dynamical response of the model

The velocity of flutter can be obtained by root locus. This is eigen-value analysis of system matrix by:

$$(35) \quad \det[A_{RS} - \lambda I] = 0.$$

where  $\lambda$  – is eigenvalue. Each eigen-mode is representing by complex conjugate pair of  $\lambda = \lambda \pm i\lambda$ . The analysis is preform according to the selected variable i.e.: velocity, controller gain and so on. Each  $\lambda$  representing eigen-mode is given as

$$(36) \quad \lambda = \omega(\gamma + i).$$

where  $\omega$  – frequency,  $\gamma$  – damping,  $i$  – complex unit. The lag root obtained by Duhamel's integral has real part only and is defined as

$$(37) \quad \lambda = \gamma_{LAG} \cong -\frac{v_{\infty} \beta_i}{c}.$$

The flutter velocity is found from complex plot of  $\lambda = f(v_{\infty})$  where any of eigenvalue cross imaginary axis of complex plot i.e.

$\text{Re}(\lambda) > 0$ . The dynamical response of model for given initial condition can be obtained aby solving Eq. (33) and (34).

## 7. Verification of open-loop model

The verification process of system was done for the following input data which are based on data collected during flutter analysis of those airplanes: Sparrow [7], Phoneix [8], Via [9], and Magic [10]. Input data:  $c=0.475\text{m}$ ;  $x_e=-0.238\text{m}$ ;  $x_k=0.249\text{m}$ ;  $m=6.814\text{kg/m}$ ;  $S_{EO}=0.856\text{kg.m/m}$ ;  $J_{EO}=0.630\text{kg.m}^2/\text{m}$ ;  $S_{\delta}=0.086\text{kg.m/m}$ ;  $J_{\delta}=0.046\text{kg.m}^2/\text{m}$ ;  $f_y=25.6\text{Hz}$ ;  $f_{\varphi}=47.2\text{Hz}$ ;  $f_{\delta}=13.7\text{Hz}$ ;  $g_y=g_{\varphi}=g_{\delta}=0.03[-]$ ;  $\rho=1.225\text{kg/m}^3$ ; where  $g$  – structural damping.

The flutter velocity of open-loop model determined by means of root locus Eq. (35) is  $V_{FL}=83.3\text{m/s}$  for plunge. The verification of model derived in this paper was done on behalf of flutter velocity comparison with one obtained by FEM software for flutter analysis MSC.Nastran, flutter analysis program developed at CTU in Prague [11] and author's K-Method [12] for the same input data. The results are listed in table 1.

| Method         | MSC.Nastran | K-Method | CTU in Prague | Root locus |
|----------------|-------------|----------|---------------|------------|
| $V_{FL}$ [m/s] | 84.1m/s     | 79.7m/s  | 86.5m/s       | 83.3 m/s   |

Table 1: Comparison of flutter velocity for different methods.

## 8. Results of closed-loop analysis

There were tested several type of control laws but only those presented here have some influence on flutter velocity. The main request for control law is to damped an airfoil oscillation to remain in steady flight above open-loop flutter velocity. The controller has to be also design so that does not respond on pilot control inputs for maneuvering of airplane or deformation of aircraft structure caused by turn maneuver. Practically this means not to respond in low frequencies, approximately up to 2Hz. The following table 2 presents the results of analyzed control law and obtained flutter velocities. The table also shows an angular rotation of supplementary control surface as a verification criterion of design correctness.

The results given by Gain controller doesn't satisfy the request not to act in low frequencies. It was used for initial preview into the behavior of the model and for check if the idea of flutter suppression by supplementary control surface is possible. It also show that has to be investigate a positive feedback of controller, given by non-zero constant  $R_i=+1$ , because the negative feedback caused decreasing the critical flutter velocity in some cases.

The highest closed-loop flutter velocity is for test case ID 11 and 20 with control variable of  $\dot{\varphi}$ . For this cases the flutter will not occur at all, the critical speed represents a torsional divergence velocity because  $\text{Re}(\lambda) > 0$  for the lag root. But due the unacceptable high rotation of supplementary control surface at low velocity this options can't be used.

The best trade-off between flutter velocity and rotation  $\Theta$  is test case ID 31 for Band pass controller with  $\dot{y}$  control variable where flutter velocity is  $187\text{m/s}$  and  $\Theta=\pm 20^\circ$  for high velocity and  $\pm 40^\circ$  for low velocity. The root locus and dynamical response of test case ID 31 is on figure 3.

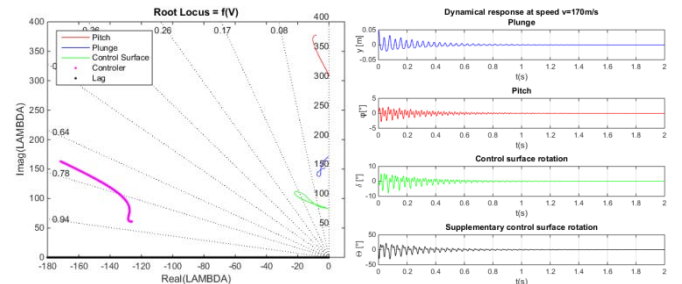


Fig. 3 Root locus and dynamical response for closed-loop test case ID 31

## 9. Experiment

There was carried out some works on experimental verification of this concept of flutter suppression. A very first model for study of flutter mechanism was built from thin plastic plate. A car was used for execution of an experiment and the flutter occurs at velocity about 16.6m/s.

There was build another experimental model for testing in aerodynamic wind tunnel at CTU in Prague. It was made from balsa and glass fiber composite with reinforcement beam flange from carbon composite. The model had two control surface and one supplementary control surface in the middle driven by controller. Figure 4 show ground vibration test of this model for determining the model input data for mathematical model. This model was destroyed during the experimental determination of open-loop flutter velocity. The problem was to high velocity increment. Construction of another experimental model is in progress.

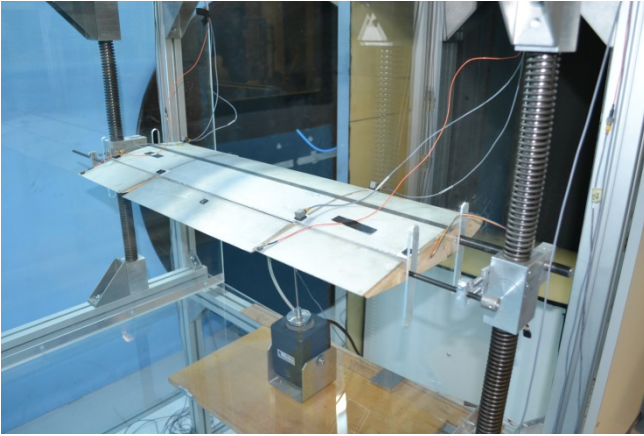


Fig. 4 Ground vibration test of experimental model

## 10. Conclusion

On behalf of mathematical model derived here the idea of flutter suppression by supplementary control surface can be realized. The analytical calculation shows that the flutter was not

suppress but moved to higher velocity only. For the best test cases the velocity was shifted about 225%. Future work on mathematical model will be aimed on inclusion of wing span, unsteady hinge moment of supplementary control surface. There have to be also considered an actuator dynamic and its time delay, sensor location and their noise.

## References

- [1] Ramsey, J.G., NASA Aeroelasticity Handbook, Vol.2: Design Guides, Part 2, NASA/TP-2006-212490/VOL2/PART2.
- [2] Sutherland, A.N., "A Small Scale Pitch-Plunge Flutter Model for Active Flutter Control Research", 26<sup>th</sup> International Congress of the Aeronautical Science, 2008.
- [3] Karpel, M., "Design for Active Flutter Suppression and Gust Alleviation Using State-Space Aeroelastic Modeling", Journal of Aircraft, Vol. 19, No.3, 1982 p.221-227.
- [4] Theodorsen, T., "General Theory of Aerodynamic Instability and the Mechanism of Flutter" NACA Report no. 496, 1935.
- [5] Leishman, J. G., "Unsteady Lift of Flapped Airfoil by Indicial Concepts" Journal of Aircraft, Vol.31, No.2, 1994, p. 288-297.
- [6] Edwards, J. W., Ashley, H., and Breakwell, J.V., "Unsteady Aerodynamic Modeling for Arbitrary Motions", AIAA Journal, Vol. 17, No. 4, 1979, p.365-374.
- [7] Kratochvíl, A., Sommer, T., Slavík, S., „Flutter analysis of wing of the Sparrow-ML" Czech Technical University in Prague, 2013, Report no. VZP/ULT/57/2013
- [8] Kratochvíl, A., Sommer, T., Slavík, S., „Flutter analysis of wing of the airplane PHONEIX with 15m wing-span" Czech Technical University in Prague, 2015, Report no. TZP/ULT/9/2015
- [9] Kratochvíl, A., Sommer, T., Slavík, S., „Flutter Analysis of the VIA NG6 Airplane" Czech Technical University in Prague, 2015, Report no. TZP/ULT/46/2014
- [10] Kratochvíl, A., Sommer, T., Slavík, S., „Flutter analysis of the SR-01 MAGIC UL" Czech Technical University in Prague, 2012, Report no. TZP/ULT/21/2012
- [11] Slavík, S., „Direct p-k scheme of wing and empennage flutter characteristics with control surfaces of small sport aircraft", Software, Czech Technical University in Prague, 2010, Id ASW/CLKV/109/2010
- [12] Kratochvíl, A., „2D\_FlutterModel - 3DOF", Software, Czech Technical University in Prague, 2012, Id ASW/ULT/28/2012

| ID                                         | Controller transfer function                                                                                                | Control variable | Non-zero constant $R_i$ | Constants of controller                          | $V_{\infty}$ [m/s] | $\Theta$ [°]     | $\Theta$ [°]     |
|--------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------|------------------|-------------------------|--------------------------------------------------|--------------------|------------------|------------------|
| Table 2: Results from closed-loop analysis |                                                                                                                             |                  |                         |                                                  |                    |                  |                  |
| 1.                                         | Gain controller<br>$TF_G = G$                                                                                               | $y$              | $R_1 = -1$              | $G=16$                                           | 208                | $\pm 30^\circ$   | $\pm 40^\circ$   |
| 2.                                         |                                                                                                                             | $\varphi$        | $R_2 = -1$              | $G=24$                                           | 159                | $\pm 50^\circ$   | $\pm 40^\circ$   |
| 3.                                         |                                                                                                                             | $\delta$         | $R_3 = +1$              | $G=4.5$                                          | 156                | $\pm 50^\circ$   | $\pm 60^\circ$   |
| 4.                                         |                                                                                                                             | $\dot{y}$        | $R_4 = +1$              | $G=3.5$                                          | 33                 | $\pm 1000^\circ$ | $\pm 1000^\circ$ |
| 5.                                         |                                                                                                                             | $\dot{\varphi}$  | $R_5 = +1$              | $G=0.2$                                          | 84                 | $\pm 50^\circ$   | $\pm 75^\circ$   |
| 6.                                         |                                                                                                                             | $\dot{\delta}$   | $R_6 = -1$              | $G=0.018$                                        | 91                 | $\pm 40^\circ$   | $\pm 30^\circ$   |
| 7.                                         | P-I-D controller<br>$TF_{PID} = G \left( 1 + T_D s + \frac{1}{T_I s} \right)$<br>where $T_D=1/\omega_D$<br>$T_I=1/\omega_I$ | $y$              | $R_1 = -1$              | $G=3.00; \omega_D=5; \omega_I=31$                | 192                | $\pm 40^\circ$   | $\pm 50^\circ$   |
| 8.                                         |                                                                                                                             | $\varphi$        | $R_2 = -1$              | $G=3.08; \omega_D=7; \omega_I=104$               | 87                 | $\pm 60^\circ$   | $\pm 60^\circ$   |
| 9.                                         |                                                                                                                             | $\delta$         | $R_3 = -1$              | $G=0.20; \omega_D=5; \omega_I=500$               | 260                | $\pm 40^\circ$   | $\pm 60^\circ$   |
| 10.                                        |                                                                                                                             | $\dot{y}$        | $R_4 = +1$              | $G=0.20; \omega_D=19; \omega_I=500$              | 120                | $\pm 50^\circ$   | $\pm 60^\circ$   |
| 11.                                        |                                                                                                                             | $\dot{\varphi}$  | $R_5 = +1$              | $G=0.03; \omega_D=20; \omega_I=500$              | 525                | $\pm 10^\circ$   | $\pm 90^\circ$   |
| 12.                                        |                                                                                                                             | $\dot{\delta}$   | $R_6 = -1$              | $G=0.03; \omega_D=120; \omega_I=200$             | 261                | $\pm 30^\circ$   | $\pm 80^\circ$   |
| 13.                                        |                                                                                                                             | $\ddot{y}$       | $R_7 = +1$              | $G=2.1 \cdot 10^{-5}; \omega_D=10; \omega_I=300$ | 87                 | $\pm 20^\circ$   | $\pm 20^\circ$   |
| 14.                                        |                                                                                                                             | $\ddot{\varphi}$ | $R_8 = -1$              | $G=7.8 \cdot 10^{-6}; \omega_D=3; \omega_I=300$  | 85                 | $\pm 80^\circ$   | $\pm 80^\circ$   |
| 15.                                        |                                                                                                                             | $\ddot{\delta}$  | $R_9 = -1$              | $G=8.0 \cdot 10^{-6}; \omega_D=10; \omega_I=200$ | 86                 | $\pm 60^\circ$   | $\pm 50^\circ$   |
| 16.                                        | High pass controller<br>$TF_{H-P} = G \frac{T_s}{T_s + 1}$<br>where $T=1/\omega_c$                                          | $y$              | $R_1 = -1$              | $G=30.0; \omega_c=50$                            | 132                | $\pm 50^\circ$   | $\pm 50^\circ$   |
| 17.                                        |                                                                                                                             | $\varphi$        | $R_2 = -1$              | $G=30.0; \omega_c=50$                            | 94                 | $\pm 60^\circ$   | $\pm 50^\circ$   |
| 18.                                        |                                                                                                                             | $\delta$         | $R_3 = -1$              | $G=13; \omega_c=150$                             | 268                | $\pm 60^\circ$   | $\pm 100^\circ$  |
| 19.                                        |                                                                                                                             | $\dot{y}$        | $R_4 = +1$              | $G=0.42; \omega_c=250$                           | 126                | $\pm 50^\circ$   | $\pm 90^\circ$   |
| 20.                                        |                                                                                                                             | $\dot{\varphi}$  | $R_5 = +1$              | $G=0.42; \omega_c=250$                           | 531                | $\pm 35^\circ$   | $\pm 130^\circ$  |
| 21.                                        |                                                                                                                             | $\dot{\delta}$   | $R_6 = -1$              | $G=0.04; \omega_c=80$                            | 261                | $\pm 30^\circ$   | $\pm 60^\circ$   |
| 22.                                        |                                                                                                                             | $\ddot{y}$       | $R_7 = +1$              | $G=0.001; \omega_c=100$                          | 102                | $\pm 50^\circ$   | $\pm 50^\circ$   |
| 23.                                        |                                                                                                                             | $\ddot{\varphi}$ | $R_8 = -1$              | $G=0.0045; \omega_c=50$                          | 85                 | $\pm 60^\circ$   | $\pm 60^\circ$   |
| 24.                                        |                                                                                                                             | $\ddot{\delta}$  | $R_9 = -1$              | $G=0.0002; \omega_c=50$                          | 94                 | $\pm 100^\circ$  | $\pm 90^\circ$   |
| 25.                                        | Band pass controller<br>$TF_{B-P} = G \frac{\omega^2 s}{\omega^2 + 2\xi\omega s + \omega^2}$                                | $y$              | $R_1 = -1$              | $G=0.05; \omega=145; \xi=0.3$                    | 100                | $\pm 30^\circ$   | $\pm 25^\circ$   |
| 26.                                        |                                                                                                                             | $\varphi$        | $R_2 = -1$              | $G=0.13; \omega=140; \xi=0.4$                    | 95                 | $\pm 40^\circ$   | $\pm 20^\circ$   |
| 27.                                        |                                                                                                                             | $\delta$         | $R_3 = +1$              | $G=0.01; \omega=120; \xi=0.25$                   | 103                | $\pm 50^\circ$   | $\pm 30^\circ$   |
| 28.                                        |                                                                                                                             | $\dot{y}$        | $R_4 = -1$              | $G=1.3 \cdot 10^{-4}; \omega=120; \xi=0.07$      | 91                 | $\pm 30^\circ$   | $\pm 15^\circ$   |
| 29.                                        |                                                                                                                             | $\dot{\varphi}$  | $R_5 = +1$              | $G=1.3 \cdot 10^{-4}; \omega=150; \xi=0.05$      | 90                 | $\pm 20^\circ$   | $\pm 15^\circ$   |
| 30.                                        |                                                                                                                             | $\dot{\delta}$   | $R_6 = -1$              | $G=2.0 \cdot 10^{-5}; \omega=145; \xi=0.05$      | 101                | $\pm 50^\circ$   | $\pm 20^\circ$   |
| 31.                                        |                                                                                                                             | $\ddot{y}$       | $R_7 = +1$              | $G=0.9 \cdot 10^{-5}; \omega=140; \xi=0.9$       | 187                | $\pm 20^\circ$   | $\pm 40^\circ$   |
| 32.                                        |                                                                                                                             | $\ddot{\varphi}$ | $R_8 = -1$              | $G=4.0 \cdot 10^{-6}; \omega=150; \xi=0.25$      | 85                 | $\pm 50^\circ$   | $\pm 50^\circ$   |
| 33.                                        |                                                                                                                             | $\ddot{\delta}$  | $R_9 = -1$              | $G=1.0 \cdot 10^{-6}; \omega=120; \xi=0.45$      | 106                | $\pm 50^\circ$   | $\pm 30^\circ$   |

# WAYS OF EFFICIENCY'S INCREASING OF COMPUTER GRAPHICS PRODUCTION LIFE CYCLE PROCESSES.

Assoc. Prof. Dr. Econ. Abrahamyan V.<sup>1</sup>, MA Political Science, Ter-Sargsyan R.<sup>2</sup>  
Institute of Economics and Business<sup>1</sup> - Russian-Armenian (Slavonic) University, Yerevan, Armenia  
a.vahram@mail.ru<sup>1</sup>, ter-sargsyan@inbox.ru<sup>2</sup>

## **Abstract**

*Computer graphics production is one of the most dynamic branches of IT sphere. Production life cycle optimization is an actual problem, especially for indi-producers and small companies. Research offers a solution based on efficiency's increasing of preproduction stage of life cycle.*

## **Introduction**

Creation of products of computer graphics («computer-generated imagery», for short - CGI or CG) – the unique branch of information technologies sphere adjacent to engineering, industrial design, graphic and cinematography. However the industry of computer graphics has a weak scientific and practical readiness.

Products of 3D graphics have the broadest application in many branches today: animation and film industry, design and engineering (creation of architectural models, industrial prototypes, etc.), creation of computer and console games, interfaces and utilities of the software and applications. According to J'son & Partners Consulting in 2016 the market of the game industry (70% of all content of CG) is estimated at \$91,5 billion [2].

Companies engaged in CG are carrying out difficult design, organizational and production and technological processes. For increasing level of efficiency of these processes and improvement of quality of the performed works it is necessary to optimize structure of production life cycle on time.

As the CG industry is rather specific and new, there are no due academic and applied researches on this perspective. The scope of research seems actual from the scientific point of view and having applied value. Results of research may be interesting to CGI specialists and businessmen.

The main subjects of CG production are independent studios and the specialized divisions of the companies (developers of the interactive software, animation and cinema studios).

Computer graphics studio is the organization, carrying-out activities for creation of the digital visual content, including:

1) Materials on visual development. Project visual development is the process of search and implementation of the design and art solutions. This stage includes creation of technical drawings, a concept art, development of the main design of the project. On the basis of the created "package" of materials is enable to start project technical realization.

2) Materials (3D models, animation files, etc.) and technical attributes to them created in specialized software. Attributes settings for models could be "rig & skin", simulations of the physical processes, material set up and "shading", etc.

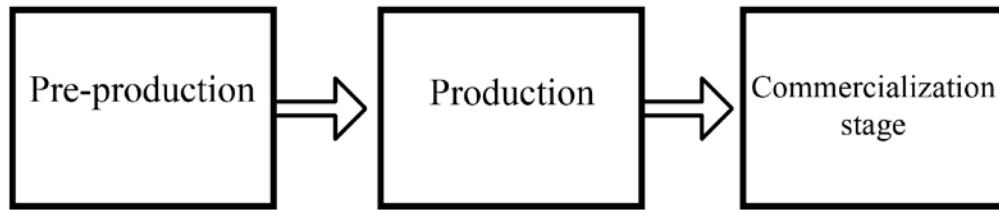
3) Visualized, rendered or post-processed video series or images.

## **CGI project life cycle**

This research is based on studying of logistic system of the animation studio which is carrying out functions of production of the animation movie with use of technology of three-dimensional computer graphics (further – "project").

Life cycle of the project (creation of the animation movie) has three main stages – preproduction, production, post-production, and has average duration in 2.5-3 years.

The schematic structure of life cycle of creation of the animation movie has the following appearance (fig. 1).



*Fig. 1. Life cycle of the animation movie.*

At a preproduction stage are performed the following works:

- story and visual development (including work on scenario, storyboard, concept art);
- analyzing of technical problems, specific to this project, possible modernization of the equipment and software;
- researches and development of technical solutions for the project (so called “R&D”);
- determination of terms of work for each division of the company at each production phase.

Production stage includes:

- creation of 3D virtual models of characters and environment;
- creation of rig and skin of a virtual exoskeleton of objects, characters;
- animation (manual or combined with the technology of "motion capture");
- simulation of special effects;
- preparation of scenes for rendering ("layout", lighting and "scene setup");
- process of final image visualization (rendering).
- montage;
- image converting to “stereo” (a possibility of viewing of materials in the "Real 3D" format);
- color correction and post-processing.

Commercialization stage means:

- integration of the materials into the final project (the movie, the interactive software, etc.);
- release and sales.

CG developing studio carries out subcontract activity. Therefore life cycle of the project comes to the end with delivery of the stipulated package of materials for their further integration into the movie. The release, distribution, sales and the accompanying service of the project isn't function of the producer.

Activities at each stage are carrying out by the relevant divisions and specialists of studio

under the general technical guide of the supervisor and coordination the project manager.

### **CGI projects production efficiency increasing**

The sphere of computer graphics develops extremely dynamically. Produced content has to meet the growing requirements of the market. The period of moral obsolescence of production of CG is made by about 3 years. The major factors influencing process of moral obsolescence of production are:

- dynamics of the sphere of material equipment the quality and quantitative indices of products allowing to increase (emergence of more powerful computing capacities, development of services of "cloud" rendering, creation of the modernized equipment for movement "capture" and three-dimensional scanning, etc.)
- development and improvement of the software in branch (updating existing and emergence of new CG creation software).
- relevance of visual decisions (production of CG has to meet the requirements and expectations of the market formed by generally large companies of industry).

Level of efficiency and competitiveness of the enterprises of industry directly depends on economically reasonable formation and realization of necessary innovative policy. Within this policy formation of the comprehensive program on development and deployment of new production, new technological processes and methods of the organization of productions is necessary. Each new project of the companies requires innovative solutions thanks to which the balance of three key components is provided: quality, time, resources.

For this purpose the technical director in close cooperation with R&D department carries out monitoring of the software market, various utilities, material and technical resources and the most successful realized projects in the sphere of

computer graphics. On the basis of results of their analysis possible decisions for carrying out innovative transformations are fulfilled and tested. Project manager creates the program of a technological chain's changing ("project pipeline") and terms of realization of each stage of the project.

Very few CG companies can increase production efficiency by developing own unique software. That is connected with attraction of large volume of resources. For example Walt Disney animation studio thanks to own programs of global lighting "Hyperion" and render-management "Koda" could achieve an indicator in 1,1 million render-hours a day. For comparison, cumulative need of the previous project of studio made 11,5 million render-hours [4]. New technology would allow to finish visualization of the previous project in 10 days, instead of 3 months put in the project.

The vast majority of CG producers is forced to use the software which is in open access and distributed according to commercial licenses. The similar state of affairs results in formal technological equality of the companies.

Achievement of competitive advantage in the production relation is possible only by means of increase of optimization of structure of life cycle of the project in time.

Using of the economic-mathematical models (EMM) seems useful for determination of technological labor input sizes of production at various stages (structural technological labor input) and sizes of material and production inputs.

It's necessary to apply logistic principles of the organization of the processes allowing to provide due to system approach coordination of the performed works between various structural divisions of animation studio at project production. Introduction of the concept of optimization of innovative production in time of Time-based Logistics (TBL) allows to create optimum structure of life cycle of production of the animation movie.

The structure of CG project life cycle (the animation movie on the basis of technologies of 3D graphics) can be presented the next graphic way (fig. 2)

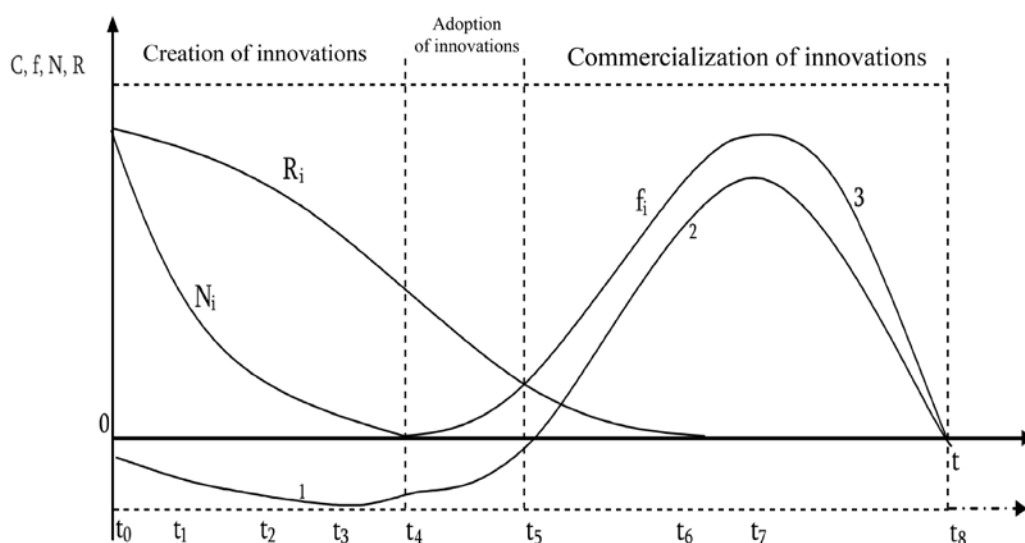


Fig.2 CG-elements containing project life cycle.

On graphics: C - expenses (income), t - time,  $f_i$  - function of life cycle i-oh innovative production, R - the risk phenomena at introduction in production i-oh innovative production, N - the uncertain phenomena at introduction in production i-oh innovative production,  $t_0$  - time of emergence of ideas for development and deployment in production i-oh innovative production,  $t_1$  - time of formation of the concept of the project,  $t_2$  - the analysis of the market, the present resources,

definition of possible technological solutions of the project,  $t_3$  - time of performance of research and developmental works with the purpose of technical training of production (end of preproduction),  $t_4$  - time of implementation of the project (a stage of production and post-processing),  $t_5$  - time of an entrance of this innovative production for the market,  $t_6$  - time of fixing of positions of this innovative production in the market,  $t_7$  - time of mass providing a market

demand for this production,  $t_8$  - time of moral obsolescence of this production and its removal from production.

1 - capital investments (one-time costs) of implementation of this innovative project, 2 - production expenses of production of innovative production, 3 – the income from realization of innovative production.

As it was noted above, the computer graphics isn't independent production and has certain terms of moral obsolescence. In structure of life cycle the stage of commercialization is invariable. Certain restrictions are connected also with a production stage. Productions can't be accelerated in a type of the CG existing technologies of creation. Increase of productivity due to extensive quantitative increase in staff of the organization and material and technical resources are extensive doesn't seems effective.

Reduction of terms of implementation of the project is possible due to optimization of a preproduction stage, since research and development, and also technical training of the beginning of production.

At the stage of research and development the most resource-intensive works are on technical training of production and development of innovative production.

Optimization of a preproduction provides development of intra studio technological documentation (technical project), creation of the database of repeated use (three-dimensional models, animation libraries, etc.).

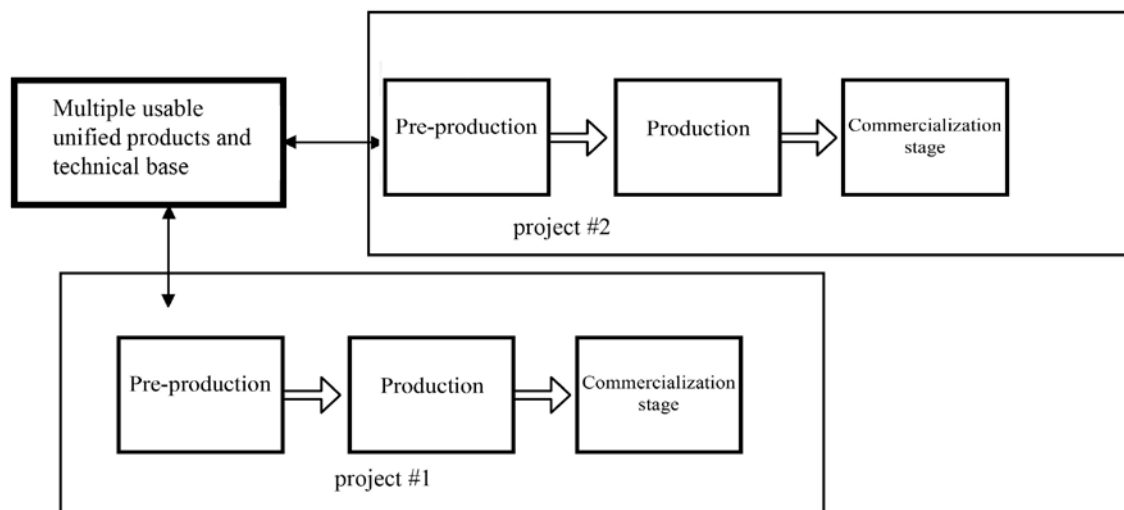
Competently organized preproduction stage gives the chance to determine the size of the resources necessary for design and introduction in

production of new production, more precisely to define efficiency of the developed project, to estimate a possibility of his realization by own forces, promotes improvement of structure of life cycle of new production on time, to avoid technical failures by production.

During pre-counting of machine-hours for the subsequent rendering it is necessary to carry out tests with various ways of in-scene lighting, methods of texturing and shading, the miscalculation of physical and correct simulation of effects and objects. It allows to define initially correctly methodology of implementation of the project and to determine terms for each of production phases. The correct assessment of necessary production capacities and the present human resource allows to count more effectively need of modernization of material resources and increase in staff of the company that in turn allows to reduce expenses.

Results of research work for one project can remain actual from two to three years (the period of high-quality changes in the sphere of the software). Material and labor inputs at this stage make considerable part from all project. Results of a preproduction in the form of organizational solutions and technical practices ("software scripts") can be reused. The solution of technical and technological problems at a stage of development allows to optimize structure of life cycle of the following realized project due to reduction of a preproduction that promotes increase of efficiency of innovative process.

The most effective for animation studio implementation of two parallel projects, seems the crossed stages of production (fig. 3)



*Fig.3. Parallel production life cycle of projects with the same research base*

On condition of the effective organization of logistic and organizational processes for every second project need for a stage of research developments disappears. Thanks to what duration of a production cycle of the second project makes 2 years. Taking into account terms of moral obsolescence of products of CG (3 years) the offered way of the organization of production allows to sell in parallel two CG projects answering to the demand which is present at branch. Creation of the unified method of the organization of a preproduction stage allows to use partially available materials and technical practices for the subsequent projects of studio on the following three-year production cycle. What in turn, will allow to increase the level of efficiency of innovative processes.

### **Conclusion**

Efficiency of the offered method of the organization of production at animation studio is defined by the following indicators:

- duration of a preproduction stage of life cycle of the animation movie for the second project is cut by half and makes 0,5 years;
- the account part of the budget of the second project as regards the salary fund decreases (on average by 25%);
- parallel implementation of two projects allows to minimize the expenses connected with depreciation and modernization of technical resources and the software (need of purchase or paid updating of the used software, replacements account of computing capacities, etc. disappears)

Parallel production of the animation movies having the general preproduction base allows to reduce prime cost of the second project and to increase operating profit of studio of computer graphics.

### **References:**

- [1] Abramyan V. G. Logistics: management of business processes in the integrated logistic chains of deliveries. RAU publishing, Yerevan, 2015, 320 pages.
- [2] Ulyanova N. Rosigroekport. Business magazine, M., 02/02/2015 g.
- [3] J'son & Parthners Management Consultancy newsletter Russia's on-line game market, 10/2013.
- [4] Oliver Franklin-Wallis. How Disney redesigned its animation toolkit. [www.wired.co.uk](http://www.wired.co.uk), 30/11/2014.

# DRIVER HEALTH AND TRAFFIC SAFETY ON THE TOURIST ROUTES

## ЗДОРОВЬЕ ВОДИТЕЛЯ И БЕЗОПАСНОСТЬ ДВИЖЕНИЯ НА ТУРИСТИЧЕСКИХ МАРШРУТАХ

Assoc. Prof. Dr. Chogovadze J.<sup>1</sup>, Prof. Dr. Kochadze T.<sup>1</sup>, student Chogovadze L.<sup>1</sup>, student Kochadze A.<sup>2</sup>

Akaki Tsereteli State University<sup>1</sup> - Kutaisi, Georgia

Tbilisi State Medical University<sup>2</sup> - Tbilisi, Georgia

E-mail: Djumberi54@gmail.com ; Temko1954@mail.ru ; chogovadze.lekso@mail.ru ; ana.kochadze@yahoo.com

**Abstract:** Based on the results of studies carried out in the field conditions, there are given some recommendations for drivers of vehicles moving on tourist routes with mountain road conditions, which will reduce likelihood of traffic accidents for them.

The paper also describes the results of studies carried out in accordance with the methodology of health check of drivers of vehicles moving on the tourist routes. As the evaluation parameters, there have been used several indexes as follows: the harmony of driver's body structure and his/her physical development was evaluated by Quetelet-2 index; death-birth and power indexes were used for evaluation of the power of the apparatus of external respiration and hand muscle strength, accordingly; the nature of nervous vegetal regulation was determined by means of systolic and diastolic pressure and chest compression frequency of hemodynamics indices; for evaluating the adaptation level by Kerdo index and Robinson index there was used the screening procedure.

Reliability of driver depends not only on his/her qualification and experience, but the state of his/her health and ability to work are of high importance as well.

**KEY WORDS:** VEHICLE'S DRIVER; TOURIST ROUTE; VEGETAL REGULATION INDEX; HEMODYNAMICS INDICES; SYSTOLIC AND DIASTOLIC PRESSURE; CHEST COMPRESSION FREQUENCY; ADAPTATIONAL LEVEL

### 1. Introduction

The driver is an essential link of the "driver-car-road-environment" system, its operator particularly [1]. The driver receives basic information on road conditions through observation. A great deal of information and its nature, which is constantly changing, for example when driving in mountain environments, does not allow for its timely absorbing and processing, and consequently for making the right decision. This process is especially pronounced at psycho-physiological changes in driver's organism.

The system of organizing traffic safety health-care envisages a complex of the actions, which includes both medical prevention of road accidents and provision of medical assistance after these accidents.

One of the most fundamental factors of traffic safety is the health of the driver.

A person's organism has specific requirements when driving in mountain environments. At an altitude of more than three kilometers, a person has trouble breathing because of oxygen deficiency. When driving for long period of time in mountain environments, oxygen deficiency leads us to headaches, reduction in sight and hearing, disorders of digestive system and a number of undesirable effects. All this leads to rapid and severe fatigue of driver.

Travelling in tourist destinations existing in mountains gives a great pleasure to many car enthusiasts (Pic. 1). Of course, overcoming the breathtaking ascents and downhill sections on the twisting mountain roads is much more interesting, as well as enjoying views over the beautiful mountains.

### 2. Preconditions and means for resolving the problem

Before starting driving on the mountain roads (Pic. 1), the tourist-drivers have to make an in-depth analysis of all those difficulties, which they could face when driving on the mountain roads, as well as it is important to continuously improve skills and moral-psychological qualities of driver.

To that end, the driver has to take into account several recommendations as follows:

**To accurately assess your own capacities.** For example, if the driver of another vehicle outpaces you, do not step on the gas and do not compete with him! Let him outpace you, and remember that in such case the increased speed is just a direct path to the hospital. Alternately, at best, you may meet this driver on the pass being too tired and nervous, thinking about what to do with this

damaged car, since studies of transport-tourist routes road infrastructure of the Imereti region have shown that service centers are mostly situated only in cities and sometimes in densely populated areas.



**Pic. 1.** An interesting view of the mountain road section of the Imereti region's transport-tourist route.

**Inadequate hazard assessment.** The mountain road is full of surprises. For example, studies of the "Kutaisi-Terjola-Tkibuli-Nikotrtsminda-Kutaisi" transport-tourist route have shown that the traffic flow on several tens kilometers of the most dangerous section of the mountain spiral highway is too small, and sometimes there is no oncoming traffic in front. In case of a drivable car, the driver begins to step on the gas. Due to changes in the trajectory of the movement, the possibility of driving onto the oncoming traffic increases that is very dangerous. Because of the insistence on getting fast through this dangerous turn (Pic. 2), the centrifugal forces acting on a car increase lateral skid, and in case of belated braking, the vehicle can suddenly end up at the center line of the closed left sharp turn the tourist bus is following, and, as a result, the probability of tragic traffic accident is too high.

Thus, it is essential that the tourist bus drivers have experience with driving on these mountain roads, or/and they must be retrained by appropriate methodology. Practical and theoretical trainings should enable drivers to drive on the mountain roads safely and with a low likelihood of traffic accident.



**Pic. 2.** The dangerous turn of the Imereti region's transport-tourist route

When driving on the mountain roads, the most important factor is the strict observance of traffic rules by drivers of vehicles, as well as their health check system.

During intensive traffic flow in complicated mountain environments, high demands are placed to the state of health of a driver. In order to define driver's health end-points, he is needed to have a medical check-up. Proper medical check-ups before setting out on the journeys represent an essential link in the prevention of road traffic accidents.

Any person, who is not accustomed to mountain environments, may even have the mild or severe forms of mountain sickness. So, those people, who are physically unprepared and are in poor health, especially the drivers, must comply with safety regulations. Some people are adapting rapidly to oxygen deficiency, but some of them need a long period of adjustment.

Health end-points, which may represent the basis for refusing the vehicle's driver journey, are as follows:

- The presence of severe symptoms or complications of chronic diseases;
- Increasing or reducing heart rate and variation of the upper and lower rates of blood pressure that is typical of all tested drivers;
- The driver is under the influence of alcohol or other preparations (narcotic drugs and psychotropic preparations), which disturb their functional status.

For a comparative analysis of morphofunctional parameters, the observations were carried out on the tourist routes on the vehicles's drivers of different age and physical abilities for the period of three three years. During the period of carrying out anthropometric screening, by meeting certain requirements, the

following have been measured: driver's height, cm; weight, kg; chest circumference S, cm; lung capacity, V; right hand size, A, cm; left hand size, B, cm; systolic pressure  $P_1$ , mm, Mmhg; diastolic pressure  $P_2$ , mm, Mmhg, heart ratio, f, beats per minute.

As the evaluation parameter there has been used the body-weight index, or Quetelet-2 index, which is calculated by the formula:

$$I_m = \frac{M}{h^2}$$

The body-weight index allows for assessing the level of compliance of the body-weight with its height, in other words the harmony of its physical development. The body-weight index evaluates indirectly if the mass of a person is sufficient, normal or excessive. According to foreign medical scientists, variation of the body-weight index within  $25-27 \text{ kg/m}^2$  for men is ideal. As the evaluation parameter there also are used: the birth-death ratio  $I_s = V/M$ , which characterizes the power of the apparatus of external respiration, but the power index  $I_p = A/M$ , determines the hand muscle strength.

Of high importance for the drivers of tourist buses in mountain environments is calculation of Kerdo index [2], or the index of nature of nervous vegetal regulation by the formula:

$$I_k = 1 - \frac{P_2}{f}$$

For quantitative evaluation of energy potential of human organism, there is used the Robinson index [4], which is calculated by the formula:

$$I_r = \frac{f \cdot P_1}{100}$$

The Robinson index characterizes the heart systolic work. The larger is this index for physical load, the higher is functional capacity of heart muscle.

For evaluating the adaptation level, there was used the screening procedure, which is calculated by the formula:

$$K = 0,011x f + 0,014x P_1 + 0,008x P_2 + 0,014x W + 0,009x M + 0,004x C - 0,009x h - 0,273,$$

where, W- age (years); C- gender (male -, female - 2).

The adaptation level of human organism to the environment "health level" is classified as follows: health first level – the state is optimal, satisfactory adaptation; health second level – the adaptation mechanisms are tense; health third level – unsatisfactory adaptation level, during which there are inconsistencies with the organism functioning mechanism; health fourth level – interruption of adaptation – status of patient before or during disease [3].

Hemodynamic indices represent the criterion of cardiovascular system, which is influenced by the environmental factors. Thus, the drivers of buses moving on the tourist-transport routes in mountain environments have been subjected to a medical examination on the parameters, which affect hemodynamic indices (Table 1).

Table 1

| Comparative Analysis of Driver's Hemodynamic Indices |            |            |            |
|------------------------------------------------------|------------|------------|------------|
|                                                      | 2014       | 2015       | 2016       |
| Heart Ratio(f)                                       |            |            |            |
| 1.                                                   | 72,1±2,50  | 71,4±2,70  | 71,1±2,60  |
| 2.                                                   | 80,3±1,90  | 82,2±1,30  | 83,8±2,10  |
| 3.                                                   | 68,4±3,45  | 69,2±2,10  | 68,4±2,57  |
| 4.                                                   | 76,9±4,46  | 82,1±2,32  | 80,8±1,24  |
| 5.                                                   | 78,4±4,22  | 81,5±3,20  | 82,5±4,29  |
| Systolic Blood Pressure ( $P_1$ )                    |            |            |            |
| 1.                                                   | 118,1±4,48 | 119,5±2,27 | 121,3±2,49 |

|                                                          |            |            |            |
|----------------------------------------------------------|------------|------------|------------|
| 2.                                                       | 136,8±2,80 | 137,0±2,89 | 133,2±2,44 |
| 3.                                                       | 118,7±2,46 | 117,7±4,53 | 122,3±3,30 |
| 4.                                                       | 135,6±2,11 | 136,2±3,92 | 140,4±4,26 |
| 5.                                                       | 135,8±1,42 | 133,6±2,09 | 136,2±5,56 |
| Diastolic Blood PressureP <sub>2</sub> (P <sub>1</sub> ) |            |            |            |
| 1.                                                       | 70,2±4,44  | 74,4±3,77  | 75,3±2,87  |
| 2.                                                       | 78,3±3,88  | 78,6±3,26  | 79,3±2,71  |
| 3.                                                       | 75,2±2,55  | 78,1±3,30  | 79,1±3,16  |
| 4.                                                       | 78,1±3,40  | 81,4±4,18  | 80,7±4,88  |
| 5.                                                       | 82,1±5,32  | 84,4±4,91  | 83,4±5,10  |

It has been established that during the entire period of research, heart ratio has a narrow range of frequencies, which indicates stability and tolerance of organism.

Systolic and diastolic pressures tend to increase in line with the rise in age, especially among older drivers.

Table 2

**The values of the drivers' physical development (morphofunctional parameters) and their assessment**

| Driver           | 1    | 2     | 3     | 4     | 5     |
|------------------|------|-------|-------|-------|-------|
| Quetelet-2 index | 22,9 | 25,9  | 25,4  | 28,6  | 26,1  |
| Assessment       | 1    | 2     | 2     | 3     | 2     |
| Kerdo index      | 0,04 | 0,04  | -0,13 | 0,01  | -0,02 |
| Assessment       | 2    | 2     | 3     | 2     | 2     |
| Robinson index   | 85,3 | 111,3 | 82,1  | 109,8 | 109   |
| Assessment       | 2    | 3     | 2     | 3     | 3     |
| Adaptation level | 2,35 | 2,94  | 2,21  | 3,19  | 3,09  |
| Health level     | 1    | 2     | 1     | 3     | 2     |

Note: 1- below the norm; 2- normal value; 3- above the norm.

By Quetelet-2 index, it has been established that the drives have a harmonic ratio of the body height and weight (Table 2), the only exception is one tested patient ( $I_m = 28,6$ ). According to this parameter, he has excess weight, and another one has insufficient mass ( $I_m = 22,9$ ). So, as it is believed by psychologists, the body dysmorphic disorder may have a negative effect on human psychological health: impairment in self-assessment ability, causing depression.

The level of nervous vegetal system effect on blood vessels was assessed by Kerdo index (Table 2). The values of this index are within normal physiological parameters from 0,1 to -0,1. In addition to the driver, who had initial vegetation tonus with exuberant sympathetic effect (-0,13), one more driver has been identified with vegetonometry tendency (-0,02).

For describing the quality of the exchange-energy processes occurring in the organism and myocardial oxygen consumption, there has been used the Robinson index. The upper (111,3) and lower (82,1) values of Robinson index confirm exuberance of sympathetic or para-sympathetic vegetation nervous system, but two of them disclosed the signs of cardio-vascular system regulation disturbance (109 and 109,8), and one of them had the cardio-vascular system regulation disturbance directly.

By the ratio of health level, the has been determined the adaptation level. The lower is the value of the adaptation level parameters, the higher is health level. In general, the drivers disclosed the positive result of health assessment and adaptation capacities (Table 2): satisfactory adaptation (first health level) was disclosed by 2 drivers, in other words, their organisms have high functional capacities; 2 drivers belonged to the functional stress group (second health level; and 1 driver disclosed unsatisfactory level of adaptation.

### 3. Conclusion

Good characteristics of nervous vegetal regulation indicate the optimal level of functional reserve of regulation and self-regulation mechanisms, which ensures adaptation to the ambient environmental factors.

The rivers of buses moving on the tourist-transport routes are needed to have medical check-ups on the parameters, which affect hemodynamic indices.

Thus and so, Reliability of driver depends not only on his/her qualification and experience, but the state of his/her health and ability to work are of high importance as well.

### 4. References

1. I.S. Stepanov, Yu.Yu. Pokrovskiy, V.V. Lomakin, Yu.G. Moskal'yova. The influence of the elements of the "driver-car-road-environment" system on road traffic safety: Textbook – M.: MG TU MAMI Publ., 2011. – 171 p.
2. Kérdő I. EinausDaten der Blutzirkulationkalkulierter Index zur Beurteilung der vegetativenTonuslage // Actaneurovegetativa. — 1966. — Bd. 29. — № 2. — S. 250—268. (in German.)
3. Study of morphofunctional status of students engaged in different groups of physical education, by method of indexes. /E.A. Kaliyzhniy, Yu.G. Kuzmichev, S.V. Mikhailova and others // Electronic scientific journal "Medical University" / 2013, - Iss. 4(15), October-December. – pp. 3-9
4. Evaluation of physical development of children and teenagers: Textbook / E.S. Bogomolova and others. N. Novgorod, NGMA Publ., 2006, 260 p.

o The publication is made under support of Shota Rustaveli National Science Foundation

# DESIGN AND ANALYSIS OF THE HYDRAULIC ARM FOR MOUNTING ON A LIGHT GOODS VEHICLE

Ing. Blatnický M. PhD.<sup>1</sup>, Ing. Dižo J. PhD.<sup>1</sup>, Assoc. prof. Ing. Dalibor Barta, PhD.<sup>1</sup>  
 Faculty of Mechanical Engineering – University of Žilina, Slovak Republic<sup>1</sup>  
 miroslav.blatnicky@fstroj.uniza.sk, jan.dizo@fstroj.uniza.sk, dalibor.barta@fstroj.uniza.sk

**Abstract:** This paper is focused on numerical analysis of a hydraulic arm for use on a light goods vehicle. The designed arm is used for loading and manipulation with load up to 300 kg. Its load capacity depends on the light goods vehicle to be placed on. Great operability of this mechanism predetermines its wide application, e.g. in construction, transport, business etc. Firstly, analytical calculations of the forces, moments and reactions are introduced. Further, locations and values of the maximum stress in the structure of the designed hydraulic arm are calculated using the FEM software. These results determine the relevant data necessary for correct design functioning of the machine. After carrying out all the analyses and calculations we will be able to determine the safe use of the designed handling machine and put it into operation.

**Keywords:** HYDRAULIC ARM, FINITE ELEMENT METHOD, CALCULATION, COMPUTER SIMULATION

## 1. Introduction

An important role of engineers is to analyse the existing and newly-designed working processes in order to find an optimal way of executing the given operation. The best working process is generally considered the one that minimises the cost of performance, which can be achieved by mechanisation.

Mechanisation is an important means of increasing productivity, quality and production competitiveness. Successful introduction of mechanisation requires knowledge and understanding of physical dependencies of executed operations. Operations are executed by transfer of mechanical, electrical, pneumatic or hydraulic energy.

The aim of this paper is to achieve by analytical dimensional calculation needed dimensions of the middle part of the arm in fig. 1 (needed areas of section) and so to design lifting rotary arm, which will be placed on the pick-up automobile trailer.

After specifying of the dimensions will be possible to create the construction in CAD programme and subsequently by importing of a model into FEM programme verify the real values of stress in designed construction, already with the values, which are not at disposal at preliminary design (E.g. own mass of the construction).

## 2. Process of a hydraulic arm geometry design

Every transport and handling machine consists of three main parts:

- steel structure,
- driving mechanisms, and
- other parts (e.g. cab, steps, etc.).

The aim of this work is to design and analyse the middle part of a hydraulic arm steel structure to be mounted on a particular light goods vehicle (Fig. 1). The whole mechanism consists of three parts of steel structure. The advantage of this solution is that the operator needs driving license only for vehicles with total mass up to 3500 kg.



Fig. 1 Pick-up platform for mounting the designed hydraulic arm

## 2.1. Analysis of forces, moments and reaction on a hydraulic arm using the principle of superposition

Such a means of mechanisation utilisable not only in transport is the designed hydraulic arm, which significantly simplifies manipulation with great operativeness. With the requirement of minimum production costs we reach the most gainful output/costs ratio.

In this chapter are introduced calculations of forces and moments in joints in the entire structure. Results are necessary for cross sections design of hydraulic arm parts and also were used as the boundary conditions in the FE analysis.

Designed lengths of individual parts, resulting from construction of hydraulic cylinders in Figure 2, are as follows:  $c_1 = 1150$  mm,  $c_2 = 1150$  mm,  $c_3 = 1180$  mm,  $e_1 = e_2 = e_3 = 75$  mm,  $a_1 = a_2 = 210$  mm,  $b_1 = 774$  mm.

We consider the whole structure as mechanism with one degree of freedom. For solution of the greatest force effects the functional calculation was performed in the most efficient position of a load (Fig. 2). In this step we also obtain the needed forces of hydraulic cylinders for the equilibrium.

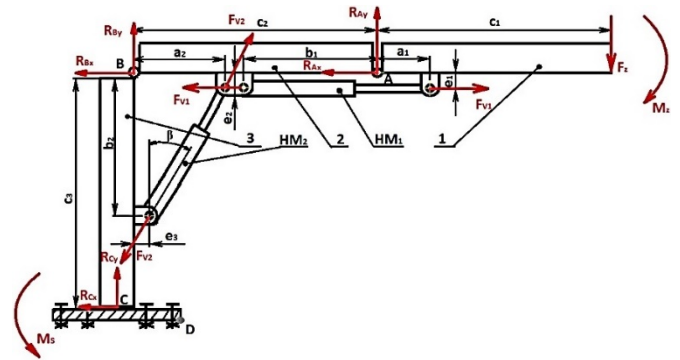


Fig. 2 Free diagram of the designed hydraulic arm

In the calculation we start from three basic equilibrium equations:

$$\sum F_{ix} = 0, \quad (1)$$

$$\sum F_{iy} = 0, \quad (2)$$

$$\sum M_i = 0. \quad (3)$$

Firstly, forces and reactions in the first part of the hydraulic arm are given (Fig. 3):

$$\sum F_{ix} = 0, \Rightarrow F_{V1} - R_{Ax} = 0, \Rightarrow R_{Ax} = F_{V1}, \quad (5)$$

$$\sum F_{iy} = 0, \Rightarrow R_{Ay} - F_z = 0, \Rightarrow R_{Ay} = F_z = m \cdot g = 300,981 = 2\,943 \text{ N}, \quad (6)$$

$$\sum M_{IA} = 0, \Rightarrow -F_z \cdot c_1 + F_{V1} \cdot e_1 = 0, \Rightarrow F_{V1} = \frac{F_z \cdot c_1}{e_1} = \frac{2\,943 \cdot 1\,150}{75} = 45\,126 \text{ N}. \quad (7)$$

Calculation of reaction values in the middle part of the hydraulic arm is based on Fig. 4.

The angle  $\beta$  we calculate according to eq. (8)

$$\beta = tg^{-1} \cdot \frac{a_2 - e_3}{b_2 - e_2} = tg^{-1} \cdot \frac{210 - 75}{774 - 75} = 10,931^\circ. \quad (8)$$

Then, from equilibrium equations we obtain:

$$\sum F_{ix} = 0 \Rightarrow R_{Ax} - R_{Bx} + F_{V2} \cdot \sin\beta - F_{V1} = 0 \Rightarrow \quad (9)$$

$$R_{Bx} = R_{Ax} + F_{V2} \cdot \sin\beta - F_{V1},$$

$$\sum F_{iy} = 0, \Rightarrow -R_{Ay} - R_{By} + F_{V2} \cdot \cos\beta = 0 \Rightarrow \quad (10)$$

$$R_{By} = F_{V2} \cdot \cos\beta - R_{Ay},$$

$$\begin{aligned} \sum M_{IB} = 0 &\Rightarrow F_{V2} \cdot a_2 \cdot \cos\beta + F_{V2} \cdot e_2 \cdot \sin\beta - R_{Ay} \cdot c_2 - F_{V1} \cdot e_1 = 0 \\ &\Rightarrow F_{V2} = \frac{R_{Ay} \cdot c_2 + F_{V1} \cdot e_1}{\cos\beta \cdot a_2 + \sin\beta \cdot e_1} \\ &= \frac{2\,943 \cdot 1\,150 + 45\,126 \cdot 75}{\cos 10,931^\circ \cdot 210 + \sin 10,931^\circ \cdot 75} \\ &F_{V2} = 30\,710,241 \text{ N}. \end{aligned} \quad (11)$$

$$\Rightarrow R_{Bx} = 45\,126 + 30\,710,241 \cdot \sin 10,931^\circ - 45\,126 = 5\,823,482 \text{ N}, \quad (12)$$

$$\Rightarrow R_{By} = 30\,710,241 \cdot \cos 10,931^\circ - 2\,943 = 27\,210,042 \text{ N}. \quad (13)$$

Finally, calculation of forces and reactions are (Fig. 5):

$$\sum F_{ix} = 0, \Rightarrow R_{Bx} - F_{V2} \cdot \sin\beta + R_{Cx} = 0 \Rightarrow R_{Cx} = F_{V2} \cdot \sin\beta - R_{Bx} \quad (14)$$

$$R_{Bx} = 30\,710,241 \cdot \sin 10,931^\circ - 5\,823,482 = 0 \text{ N},$$

$$\sum F_{iy} = 0, \Rightarrow R_{By} - F_{V2} \cdot \cos\beta + R_{Cy} = 0, \Rightarrow R_{Cy} = F_{V2} \cdot \cos\beta - R_{By} \quad (15)$$

$$R_{Cy} = 30\,710,241 \cdot \cos 10,931^\circ - 27\,210,042 = 2\,943 \text{ N},$$

$$\sum M_{IC} = 0, \Rightarrow R_{Bx} \cdot c_3 + F_{V2} \cdot \cos\beta \cdot e_3 - F_{V2} \cdot \sin\beta \cdot (c_3 - b_2) - M_s = 0 \quad (16)$$

$$M_s = R_{Bx} \cdot c_3 + F_{V2} \cdot \cos\beta \cdot e_3 - F_{V2} \cdot \sin\beta \cdot (c_3 - b_2)$$

$$\begin{aligned} M_s &= 5\,823,482 \cdot 1\,150 + 30\,710,241 \cdot \cos \\ &\quad + 10,931^\circ \cdot 75 \\ &\quad - 30\,710,241 \cdot \sin 10,931^\circ \cdot (1\,150 \\ &\quad - 774) = 6\,768,9 \text{ Nm}. \end{aligned}$$

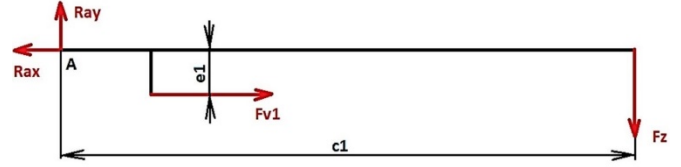


Fig. 3 Forces and reactions in the first part of the hydraulic arm

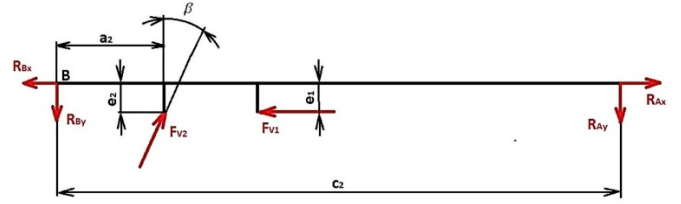


Fig. 4 Forces and reactions in the middle part of the hydraulic arm

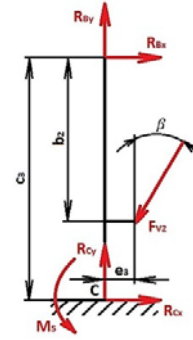


Fig. 5 Forces and reactions in the third part of the hydraulic arm

Therefore, calculated inner force effects of the mechanism (see Fig. 2) are:  $F_z = 2943 \text{ N}$ ,  $F_{V1} = 45,126 \text{ N}$ ,  $R_{Ax} = 45,126 \text{ N}$ ,  $R_{Ay} = 2943 \text{ N}$ ,  $\beta = 10,931^\circ$ ,  $F_{V2} = 30,710 \text{ N}$ ,  $R_{Bx} = 5824 \text{ N}$ ,  $R_{By} = 27,210 \text{ N}$ ,  $R_{Cy} = 2943 \text{ N}$ .

## 2.2. Choice of material, profile and dimensions of a hydraulic arm

In production of steel construction a material STN 11 423 was chosen, because of its suitable mechanical properties, guaranteed weldability and relatively low cost. Normalised hot drawn square seamless steel tubes were chosen. Provisionally, it is chosen profile TR4 HR 120x100x6-11 423.0 STN 42 5720.

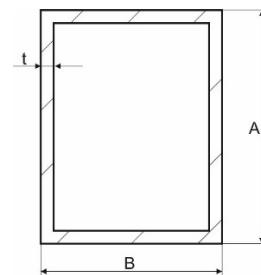


Fig. 6 Chosen steel profile for the hydraulic arm structure

Allowed combined loading of the steel construction with consideration of the safety factor is  $\sigma_{red\ dov} = 120 \text{ MPa}$ . To determine a value of stress in the middle part of the arm, an analytical calculation by classic theory of elasticity and strength is

carried out. The body considering as a beam with exact geometry and load, which value was solved in the previous step.

After defining the cross-section dimensions by analytical calculation, it is possible to build a 3D model of the hydraulic arm in CAD software. In Fig. 7 the three-dimensional model of the middle part of the hydraulic arm is shown.

The whole arm consists of three parts and to simplify the problem, numerical analysis of each part of the arm is made separately.

Further as an example, analytical calculation of the middle part of the hydraulic arm is indicated (Fig. 8). In this section the analytic calculation of the middle part of a hydraulic arm is described. Firstly, it is necessary to perform initial analytical calculation of the hydraulic arm structure. In this point we determine strain behaviour in the middle part of the hydraulic arm. Based on them the required dimensions will be it will be defined. The safety coefficient was chosen  $k = 1.5$  [-].



**Fig. 7** 3D model of the middle part of the hydraulic arm

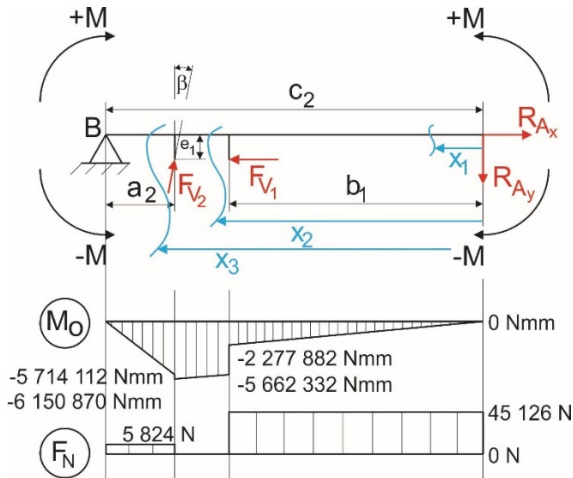
Calculation of the bending moment as a dominant loading is carried out by method of virtual cut. The beam is cut as many times as it is divided by outer loading, inner loading and by geometry, i.e. three times (Fig. 8).

In critical section, besides bending stress also tensile stress from normal force  $F_N = 5824$  N acts. The total stress then is (1):

$$\sigma_c = \frac{M_{omax}}{W_o} + \frac{F_N}{S} \quad (1)$$

$$\sigma_c = \frac{M_o max}{W_o} + \frac{F_N}{S} \quad (2)$$

By solving the equation (1), we get a value of total stress  $\sigma_c = 73.8$  MPa. Force from the hydro motor  $F_{V1}$  then loads the critical section through holder by shear stress parallel with the length of the construction and force from the hydro motor  $F_{V2}$  loads the critical section through the holder also by shear stress, but perpendicular to the length of the construction.



**Fig. 8** Pick-up platform for mounting the designed hydraulic arm

Value of the resultant shear stress is found out from the equation (2):

$$\tau_s = \sqrt{\tau_{s//}^2 + \tau_{s\perp}^2} \quad (3)$$

The resultant shear stress in the critical section then is  $\tau_s = 9$  MPa. Effective stress in the critical section is calculated according to HMH hypothesis (3):

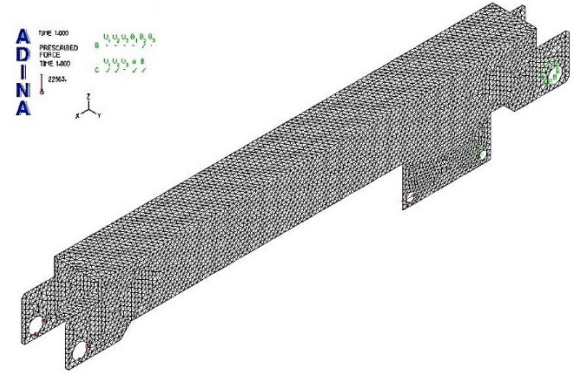
$$\sigma_{RED} = \sqrt{\sigma_c^2 + 3 \cdot \tau_s^2} \quad (4)$$

Value of the effective stress in a weld reaches by analytical method of calculation  $\sigma_{RED} = 75,5$  MPa. However, value of the resultant stress will grow because of non-considering of.

### 3. Analysis of the hydraulic arm using Finite Element Method

In this chapter, the analysis of the hydraulic arm is carried out using the FEM software.

In the programme, there was input material properties to it (elasticity modulus  $E = 2.1 \times 10^{11}$  Pa, density  $7850 \text{ kg.m}^{-3}$ , Poisson's ratio 0.3). Input boundary conditions and meshed shell construction is shown in Fig. 9. Four nodes tetrahedron elements with density of mesh 4 mm were used at meshing.

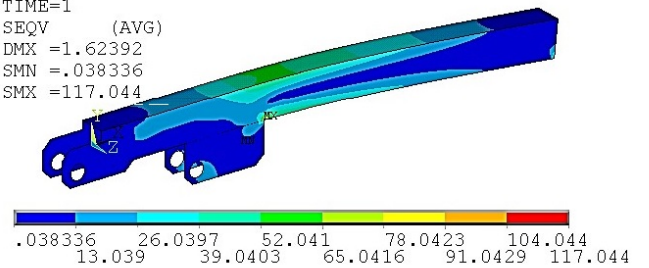


**Fig. 9** Mesh and boundary conditions in the middle part of the hydraulic arm

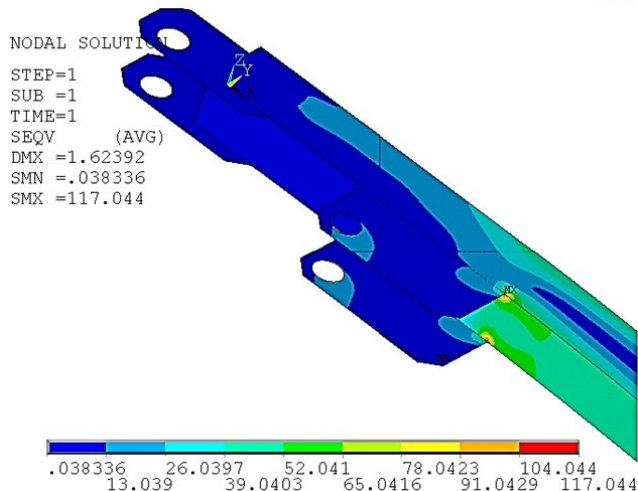
After triggering of the solver it is possible to show results in the post-processor and so von Mises's stress in the first part and in the middle part of the hydraulic arm (Fig. 10, Fig. 11, Fig. 12, Fig. 13).

NODAL SOLUTION

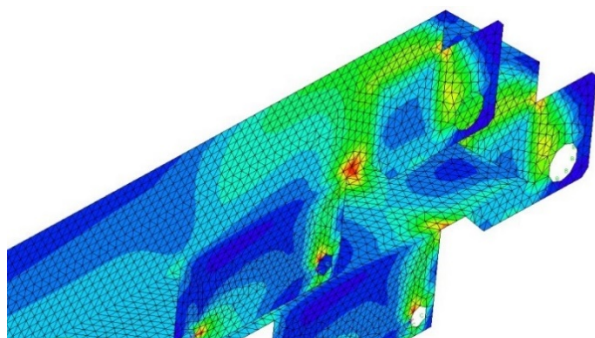
STEP=1  
SUB =1  
TIME=1  
SEQV (AVG)  
DMX =1.62392  
SMN =.038336  
SMX =117.044



**Fig. 10** Distribution of effective von Mises's stress in the first part

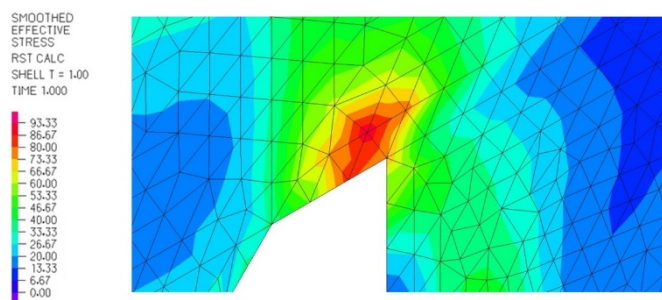


**Fig. 11** Detail of the critical section in the first part

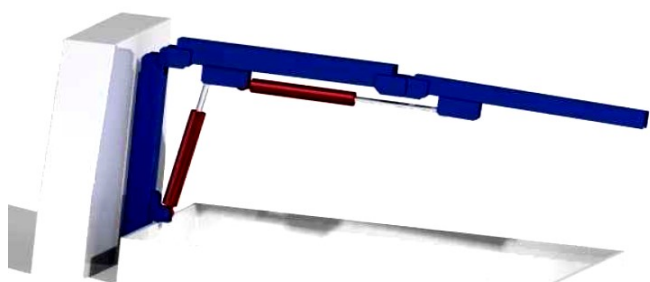


**Fig. 12** Effective von Mises's stress in the middle part of the hydraulic part

Values as well as place of the maximal stress detected by FEM programme are practically identical with those achieved by analytical calculation. Values of the stress in the critical section may be determined in FEM programme in interval 80 – 86 MPa in comparison with 75.5 MPa from analytical calculation. A detail of the critical section with distribution of the effective stress is shown in fig. 7.



**Fig. 13** Detail of distribution of the effective stress in the critical section



**Fig. 14** Lifting pivot arm with pick-up bed

## Conclusion

In the presented paper was performed design, analysis and calculation of the hydraulic arm, which was designed for mounting on a light goods vehicle. As a suitable platform for installation this arm the chassis of the off-road vehicle can be used. This equipment of a vehicle improves its operability, makes easier manipulation with loads and reduces the operational time. Although the designed structure causes decreasing the vehicle payload, still the vehicle load is enough.

As the every structure as this hydraulic arm has to be submitted analytical calculation and analyses. Well-defined force effects in the proposed mechanism is a necessary precondition for the safe operation of this device. The next step of the performing of this task is an analytical calculation of the cross-sectional dimension of each arms by using of conventional methods of elasticity and strength of material.

After designing of all dimensions creation of the 3D model was possible in a CAD software (Fig. 14). And then, the CAD model was imported into a FEM software. In this way, we could obtain adequate results of the structure strength, etc. Comparison of these two methods allows to find the overall accuracy of the solution. If unsatisfactory results had been identified, the task we could optimize before the expensive production, which in turn will contribute to the cost saving in the production of this mechanism.

## Acknowledgement

This contribution is the result of the project implementation: "Modern methods of teaching of control and diagnostic systems of engine vehicles", ITMS code 26110230107, supported by the Operational Programme Education.



The Agency  
of the Ministry of Education, Science, Research and Sport  
of the Slovak Republic  
for the Structural Funds EU



## References

- [1] Balaja, J., Broncek, J., Antala, J., Sekeresova, D. 2014. Mechanical Engineering Tables. (In Slovak). Selection Standards. Slovak Office of Standards, Metrology and Testing, 2014. ISBN 978-80-8130-039-4.
- [2] Blatnický, M., Dižo, J.: *Analysis of the hydraulic arm for use on light goods vehicle*. In: Production management and engineering sciences. - Leiden; London: CRC Press/Balkema; Taylor & Francis Group, 2016. - ISBN 978-1-138-02856-2. - S. 351-354.
- [3] Blatnický, M., Dižo, J.: *Design and analysis of hydraulic arm of light vehicle*. In: Zeszyty naukowe Instytutu Pojazdów : mechanika, ekologia, bezpieczeństwo, mechatronika. - ISSN 1642-347X. - 3 (103) / (2015), s. 5-13.
- [4] Blatnický, M., Dižo, J.: *Analysis of hydraulic arm of light vehicle*. In: TSD: XIV international technical systems degradation conference: Liptovský Mikuláš, 8 - 11 April 2015. - Warszawa: Polskie Naukowo-Techniczne Towarzystwo Exploatacyjne, 2015. - ISBN 978-83-930944-7-9. - S. 169-172.
- [5] Galliková, J., Poprocký, R.: *Use of EAM systems for effective vehicles maintenance*. In: TSD: XIV international technical systems degradation conference : Liptovský Mikuláš, 8 - 11 April 2015. - Warszawa: Polskie Naukowo-Techniczne Towarzystwo Exploatacyjne, 2015. - ISBN 978-83-930944-7-9. - S. 21-24.
- [6] Galliková, J., Poprocký, R.: *Computer-aided analysis and the consequences of failures of the selected vehicle subsystem*. In: TRANSCOM 2015: 11-th European conference of young researchers and scientists : Žilina, June 22-24, 2015, Slovak

Republic. - Žilina: University of Žilina, 2015. - ISBN 978-80-554-1048-7. - S. 58-63.

[7] Harušinec, J., Gerlici, J., Lack, T.: *Railway wheel / rail contact stress computation by means of FEM*. In: Computational and experimental methods in applied mechanics. - Ústí nad Labem: UJEP, 2012. - ISBN 978-80-7414-377-9. - S. 107-118.

[8] Harušinec, J., Gerlici, J., Lack, T.: *Normal contact stresses between railway wheel and rail assessment by means of FEM*. In: Computational and experimental methods in applied mechanics I. - Ústí nad Labem: Faculty of Production Technology and Management, UJEP, 2013. - ISBN 978-80-7414-609-1. - S. 37-46.

[9] Valčáková, L., Gerlici, J., Lack, T., Harušinec, J.: *Analyzing the plastic zone propagation in loaded material*. In: Manufacturing Technology: journal for science, research and production. ISSN 1211-4162. Vol. 18, No. 3 (2016), Pp. 208-212.

# VEHICLE- AND STAFF PRODUCTIVITY IN BUS URBAN TRANSPORT

Ing. Vít Janoš, Ph.D., Ing. Milan Kríž  
Czech Technical University in Prague, Faculty of Transportation Sciences, Czech Republic  
E-mail: janos@fd.cvut.cz; E-mail: krizmil1@fd.cvut.cz

**Abstract:** In each transport system are for its total costs key the fixed costs, deriving from regular deployed number of vehicles and drivers, related to the overall transport performance. Fixed, periodic and systematic linkages in the operational concept can achieve higher productivity of vehicles and personnel. Article explains the application of these techniques in the optimization of urban bus transport in the Czech town Jindřichův Hradec.

**KEYWORDS:** PUBLIC TRAFFIC, TRANSPORT TECHNOLOGY, BUS TRANSPORT, URBAN TRANSPORT, TIMETABLE DESIGNING, TRANSPORT EFFICIENCY, TRANSPORT PLANNING, TENDER FOR CARRIERS, VEHICLE CIRCULATION

## 1. Introduction

Bus urban transport in the Czech Republic is currently ordered in many towns. The smallest Czech town with regular public bus urban transport is Přelouč (8 200 Inhabitants).

For decision, to order or not to order bus urban transport in concrete town is the town structure, distance between transport main sources and destinations in the town and the whole attractiveness or emissivity of the town (how many people are travelling from / to the town, how important is the internal mobility).

There is a big difference in planning the operational concept of urban traffic in the big city and small town.

In large cities, it is crucial to ensure appropriate intervals in the strongest transport directions and the key issues include sufficient capacity and sufficient speed for longer distances within the city.

In smaller towns there is very wide number of traffic flows, but these traffic flows are considerably smaller and, therefore, from the perspective of public services much harder to grasp. Additionally, there are many local transport requirements - typically tied to school or significant employer - which mean subsequently fixed points, which are necessary to be served in concrete times. The result is a combination of lines with interval operation (route directions and the general demand) and lines of operation purely purposeful.

The situation is different in addition the fact that whereas in larger cities, there is usually a transport company owned by the city, which has long provided transportation services in the city (and thus falls into the category of so-called. Internal operator), in small towns such an operator usually is not, and if the volume of traffic performance exceeds 300 thousand bus km per year, is there necessary to compete these performances.

## 2. Structure and configuration of operational file in bus urban transport

In the case of urban bus transport - unlike regional bus services - falls away a question of the method of determining the structure of operational file, based on the geographic or on technological clustering. Since the space of the town, the city with its wider hinterland, or agglomeration is exactly geographically defined, remain as technological clustering by type and number of vehicles - as in bigger cities may eventually open the possibility of entering more operationally homogeneous files, in smaller towns situation leads always to formulate of just one operational file and to award of one contract.

The authors of this article have participated in the preparation of the technological structure of the operational file of bus urban transport in Czech town Jindřichův Hradec. Jindřichův Hradec is south-Bohemian town with 21460 inhabitants.

### 2.1. Operational structure before the competition

The original transport concept of urban operation in Jindřichův Hradec valid until December 31. 2015 represented a transport volume of approximately 330,000 km per year and was scheduled for 7 buses in regular circulation.

The line plan contained 5 lines with round and half round character, with different time variations and routes variations, while on any of the lines was not offered a regular interval of connections.

The entire operation of urban transport was necessary to systematically define and grasp to be able to define it in the form of a comprehensive operation file for need of competition - in terms of technical and technological parameters.

### 2.2. Operational file parameters for competition

Preparing of a new contract associated with necessity of the competition of transport carrier used the town to fundamental changes in the concept of bus urban transport. New functionality demanded by the town were as follows:

- direct leading of the lines in most important directions
- minimization of detours and higher unification of routes of single lines
- expanding operations in local parts of the town, extended operation in off-peak hours (early morning, evening hours..) and on weekends
- regular intervals on single lines; between the largest housing estates to the town center all-day basic interval of 30 minutes and in peak hours interval of 15 minutes
- creation of systematic linkages with trains at the railway station

Processing of these requirements led to a significant increase in transport performance - namely 450 000 km per year. At the same time, there was abided boundary condition, that the new concept must be able to work still with 7 buses in regular circulation. It was really such a complex combinatorial problem.

### 3. Technological structure of traffic performance in operational file

The specific content of each operating file are concrete lines, their timetables and the resulting number of vehicles, which is necessary to ensure the required transport performance.

Before assigning single lines to single operational files it is usually appropriate to revise leading of lines, not only for transportation reasons, but also for operational reasons. In the current conditions of Czech Republic, there's line management in many cases "historic", regardless of economic, socio-economic and demographic trends.

Based on the review of known facts of the various transport relations should be applied methods of line-planning leading to maximizing of the number of direct-travelling passengers.

After creating the line leading follows usually next step - forming a timetable. In urban traffic is so needful to take into account necessary intervals on lines, according to anticipated demand, and by smaller towns with longer intervals also take into account other requirements (eg. connections on trains and regional buses, the required linkages between the lines, etc.).

The standard follow-up step after creating a timetable would be to create cycles of vehicles and personnel. In this case, it is then also possible to use well-known optimization methods to minimize the number of deployed vehicles.

The author's team new approach is, that already when the timetable proposal is created, combines the operational concept with cycles of vehicles, in mutual repeating iteration steps.

After designing of the line-network and basic structure of the timetable can be done minor changes in the timetable raster, in order to allow implementation of atypical combinations of crossing vehicles under extreme time demands in the morning peak hours. In the morning peak hours were separately taken into account the requirements of the local time (starting times by significant employers, beginning of school hours). At the same time, during the morning peak hours was usually a timetable structure preserved primarily in the main transport directions and main change linkages, while in the opposite direction (contrary to a major transport streams) were used differing routes, atypical crossings between the lines, as well as pragmatic time positions, which led to the minimization of the number of vehicles in the morning peak hour of the workday. It is just a morning peak hour of the working day, which determines the number of vehicles.

Approach to the timetable creating is as follows:

- 1) defining IPT nodes and intervals, calculate the number of vehicles for "basic periodical operation"
- 2) defining a specific operation in the morning peak hours and minimizing the number of vehicles in this period; ideally for the number required in previous point 1
- 3) after the arrival of school busses, as soon as possible "timetable transition" to defined structure of periodical timetable
- 4) operational optimization and ensuring operational efficiency (breaks for drivers, refueling buses...)
- 5) adaptation of timetables in the evening hours (to minimize the number of vehicles, reduction of total working time of drivers)

The aim is to ensure maximum operational efficiency within a defined operational file.

The following figure expresses the fixed costs of the bus relative to the average daily performance.

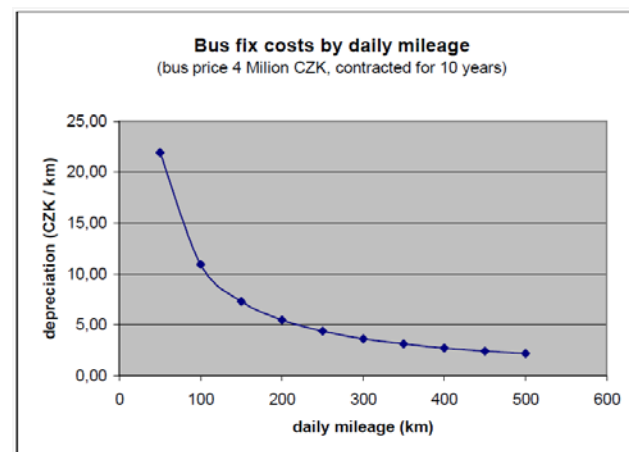


Fig. 1: Bus fix costs (depreciation) by average daily mileage

Currently, the regional bus services in the Czech Republic has held daily vehicle mileage normally about 60-130 km, in urban transport sometimes even lower. From the above figure it is apparent, that the cost curve is broken in the space daily performance of 200-300 km, which corresponds to an annual mileage of a vehicle about 70 000 to 100 000 km.

In no operational file are these limit values reached in the beginning. It is natural, since the beginning sort of performance into operational files is usually made by current timetables, which has been usually no optimized before.

#### 3.1. Case of optimized operational file of bus urban transport Jindřichův Hradec

Applying the above general approach to the optimization of the specific case of urban transport in Jindřichov Hradci went so, that it was necessary to take into account the factors listed below:

- basic interval for the peak hour (15 min) and off-peak hour (30 min) on most important lines
- determination of basic vehicle size corresponding to the capacity needs of the most occupied connection in the morning peak hour (approximately 70 passengers, which corresponds to a city bus of the 12m length)
- even though with a new concept was introduced a transit fare, the character of the line network remained as branched network (with a higher bid direct connection in most directions, at the expense of connection in a shorter interval but associated with passengers change)

The most complicated combinatorial task was assembly operational concept. The operational concept elements were tight time-anchored (eg. a request connection to trains), elements whose position directly resulted from the other of the fixed elements (eg. a requirement length of interval when a specific time slot joints unfolded from connections with rigid bonds), and finally elements whose time position was not fixed (eg. connection of smaller town parts). The operating concept was created with a direct link to the circulation of vehicles, as required with a view to achieving high operational efficiency, where was aimed to maintain 7 planned scheduled busses for regular circulation.

It was so composed a "time raster", in which were primarily occupied fixed times and requirements were subsequently occupied by combinatorial other elements with a higher degree of freedom. This process included several iterations.

Every assembly draft operational "time raster" was verified by personnel efficiency. Within the operational concept was monitored specificity consisting in fixed boundation between driver and vehicle. In the Czech environment between operational staff there is seen as a great advantage, if it is possible this boundation between driver and bus (the drivers during a work shifts do not change vehicles and every driver has "his own" bus). Although fixed bond between driver and vehicle is very strong boundary condition, which potentially hides inefficiencies, this condition was kept. Within the operational "time raster" had been as well taken into account mandatory breaks for drivers. However in the peak hours was the time for breaks utilized for embedded links (transitions and combinations of vehicles), in which by the imaginary allowed length of the drivers operation was suggested their change. Also in these combinations were used for crossing vehicles (and empty runs), since in general, empty runs can in some cases reduce the number of planned vehicles.

Single iterations during the assembly of operation "time raster" consisted in eliminating atypical combinations and subsequent reminimize empty runs. To achieve the desired result was required 5 iterations. In the resulting "time raster" operating buses are not tied to individual lines, but on individual final stops are changing between the lines.

After the formation of the final operating "time raster" were assembled circulation plans for vehicles - emerging on the principle of cyclic repetition of time raster. This laid due fixed boundation driver / vehicle the foundation for circulation plans for drivers.

The last group of optimization measures was minimizing of staffing needs. Because the proposed operational "time raster" included time for breaks for drivers, could be by using rebase "parts" of circulation plans (including the use of additional empty runs) go in selected cases to the very time-limit length of drivers work-shifts and were so composed shifts with as much time length (for two drivers alternating), and shifts to the length corresponding to the permissible driving time for one driver (without changing). These rebasings of operation "time raster", to achieve optimal results in personnel efficiency, entailed 4 iterations

The overall result is an extremely high vehicular and personnel productivity. From the original value of the average daily performance of 129 km / bus was reached 176 km daily performance / bus. On working days is deployed 7 busses and 12 drivers, on free days then 4 buses and 6 drivers.

In so comprehensively prepared form (timetables, vehicle- and drivers circulation plans) was contract for urban transport in Jindřichův Hradec tendered.

#### 4. Conclusion

The first method focused on cost reduction should take the form of increasing productivity by reducing the number of regular operated vehicle and reducing the regular number of staff - particularly the decline in fixed cost components in such a way as to prevent deterioration of service and managed to keep the revenue.

The second approach is the 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 - and just this approach was used in bus urban transport in Jindřichův Hradec.

For the operational concept in bus urban transport was a complex preparation of the contract for the tender for new carrier - bus operator.

While in the case of internal (town-owned) operator there is possible to increase operational efficiency continuously, in case of the tenders must be the operational parameters set correctly from the beginning.

This situation is in many ways even for new by bus operators participating in the tenders too, because the demands on the operational concept and quality are predetermined from the orderer. The carrier has already no possibility to optimize (or partially) operational concepts according to its operational needs. The role of carriers in this regard is already seemingly passive - however numerous carriers orient already in the new circumstances and focus their activities on the rationalization measures that allow them to cope with the prescribed requirements at the lowest cost. After the carriers have no opportunity to enter timetable preparation and requirements during the tender, they are focusing on typical operating area (suitable dislocation vehicles and personnel for contract performance, placement of technical and technological background, optimal mode of refueling buses, reduction of personnel time losses etc.)

On the example of the urban bus transport in the Czech town Jindřichův Hradec was shown, that a good and thorough preparation of a tender in public bus urban transport can significantly rise vehicle and staff productivity. With the same number of busses was created brand new timetable, with the increase in transport performance by 40%.

#### REFERENCES

1. Janoš, V. - Baudyš, K.: TECHNOLOGICAL STRUCTURE OF OPERATIONAL FILES IN REGIONAL BUS TRANSPORT FOR THE NEEDS OF THE TENDER FOR CARRIERS. In *Trans&Motauto'15 XXIII International Conference Proceedings*. Sofia: Scientific-technical union of mechanical engineering, 2015, ISSN 1310-3946
2. Kříž, M. - Michl, Z.: Public Transport Service Assessment using Macroscopic Transport Modelling. In *YTEC 2015 - Sborník příspěvků konference*. Praha: České vysoké učení technické v Praze, Fakulta dopravní, 2015, s. 120-125. ISBN 978-80-01-05791-9
3. Janoš, V. - Baudyš, K.: Transport Planning of Public Services. In *Proceedings of the 11th European Transport Congress*. Praha: České vysoké učení technické v Praze, Fakulta dopravní, 2013, . ISBN 978-80-01-05321-8

# ADVANCED VISUALISATION TECHNOLOGIES AS A TOOL IN THE AREA OF AUTOMOTIVE ENGINEERING

Ass. Prof. Tashko Rizov PhD., Prof. Milan Kjosevski PhD., Prof. Risto Tashevski PhD.

tashko.rizov@mf.edu.mk, milan.kjosevski@mf.edu.mk, risto.tashevski@mf.edu.mk

Faculty of Mechanical Engineering – Skopje, Macedonia

**Abstract:** The advanced technologies find their application in many areas of today's human life. This provides the engineers with a new ability in the area of technical visualization in different formal or informal engineering processes. Augmented and virtual reality are visualization technologies in which the virtual objects are combined with the real ones and coexist in the same space, or completely substitute the reality with computer modelled environment. In their nature, these technologies open up opportunities for their application in various processes in the area of automotive engineering. In this stage of development of these visualization technologies, initial steps have to be made for their use in engineering tasks in the area of automotive engineering. Real expectations exist that these technologies can serve as additional tools in the processes like vehicle approval or vehicle maintenance, or as an additional tool in the hands of the experts that make the crash forensics. This paper presents the results of conducted research in the direction of use of technical solutions for visualization of vehicles in different areas of the automotive engineering, presenting their positive characteristics along with their limitations.

**Keywords:** ADVANCED VISUALISATION TECHNOLOGIES, AUGMENTED REALITY, VIRTUAL REALITY, AUTOMOTIVE ENGINEERING.

## 1. Introduction

The advanced technologies find their application in many areas of today's human life. Augmented and virtual reality are visualization technologies in which the virtual objects are combined with the real ones and coexist in the same space, or completely substitute the reality with computer modelled environment. In their nature, these technologies open up opportunities for their application in the processes of crash forensics.

The advanced visualization technologies became part of the forensics process very soon after their deployment. Their use in the forensics process has been well accepted and appreciated. Based upon factual data, forensic animations can reproduce the scene and demonstrate the activity and location of vehicles, objects, and involved persons at various points in time using 3D modeled scenes and objects, 3D animations and recently augmented and virtual reality. This ability to model and visualize in 3D, has enabled the users to observe the scene from various viewpoints such as the driver's view, the victim's view or the witness' view. The advanced visualization techniques for reconstruction of crime scenes are replacing the traditional illustrations, photographs, and verbal descriptions, and they are becoming popular in today's forensics [1].

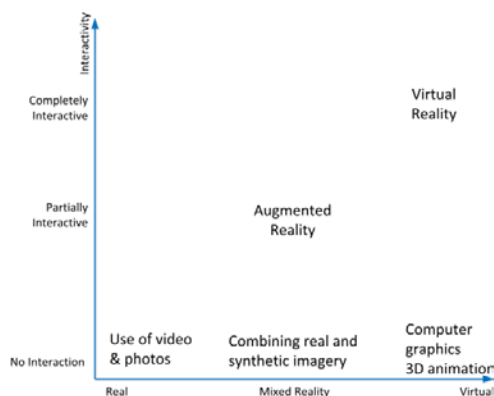


Fig. 1 Visualization techniques and their level of interactivity (Source: M. Ma, et al. 2010).

The diagram in Fig.1 presents the key difference between AR/VR and other visualization techniques and that is the level of interactivity. The use of visualization techniques like videos and photos use only real object while computer graphics and 3D animation use only virtual object. By combining the real and synthetic imagery a mixed reality is created. In all these three cases there is no user interactivity. VR and AR provide an interactive real-time 3D graphical environment that responds to user actions such as moving around the virtual world or maneuvering virtual objects. VR/AR can put the user in the driver's seat for accident reconstructions and allow the user to observe a scene from a desired point of view, which is impossible in film or photos. A VR/AR user can also, for example, play the various roles in an accident like perpetrator or witness to experience the reconstruction of the incident.

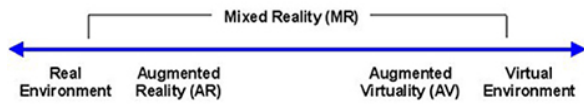
## 2. Augmented Reality

Augmented Reality (AR) is a variation of Virtual Environments (VE), or Virtual Reality as it is more commonly called. VE technologies completely immerse a user inside a synthetic environment. While immersed, the user cannot see the real world around him. In contrast, AR allows the user to see the real world, with virtual objects superimposed upon or composited with the real world. Therefore, AR supplements reality, rather than completely replacing it. Ideally, it would appear to the user that the virtual and real objects coexisted in the same space. Azuma [4] gives a more comprehensive definition of AR as a system that has the following characteristics: (1) combines real and virtual world, (2) interactive in real time and (3) registered in 3D. Augmented Reality enhances a user's perception of and interaction with the real world. The virtual objects display information that the users cannot directly detect with their own senses. The information conveyed by the virtual objects helps a user perform real-world tasks.

Augmented Reality might apply to all senses, not just sight. So far, researchers have focused on blending real and virtual images and graphics. However, AR could be extended to include sound, smell or tactile [5].

A basic design decision in building an AR system is how to accomplish the combining of real and virtual. Two basic choices are available: optical and video technologies. Each has particular

advantages and disadvantages [3].



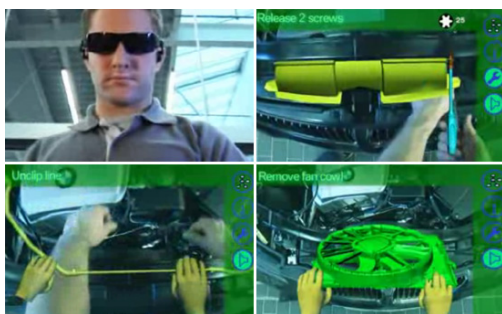
**Fig. 2** Milgram's Reality - Virtuality continuum. (source: Azuma 1997)

In the optical case, the virtual image is projected at some distance away from the user. This distance may be adjustable, although it can be fixed if the display is mounted to the user. Therefore, while the real objects are at varying distances from the user, the virtual objects are all projected to the same distance. If the virtual and real distances are not matched for the particular objects that the user is looking at, it may not be possible to clearly view both simultaneously.

A key measure of AR systems is how realistically they integrate augmentations with the real world. The software must derive real world coordinates, independent from the camera, from camera images. That process is called image registration. Image registration is one of the most basic problems currently limiting Augmented Reality applications. The objects in the real and virtual worlds must be properly aligned with respect to each other, or the illusion that the two worlds coexist will be compromised. More seriously, many applications demand accurate registration. Without accurate registration, Augmented Reality will not be accepted in many applications. Registration errors are difficult to adequately control because of the high accuracy requirements and the numerous sources of error. These sources of error can be divided into two types: static and dynamic. Static errors are the ones that cause registration errors even when the user's viewpoint and the objects in the environment remain completely still. Dynamic errors are the ones that have no effect until either the viewpoint or the objects begin moving [8].

AR is made possible by performing four basic and distinct tasks, and combining the output in a useful way. (1) Scene capture: First, the reality that should be augmented is captured using either a video-capture device such as a camera, or a see-through device such as a head-mounted display. (2) Scene identification: Secondly, the captured reality must be scanned to define the exact position where the virtual content should be embedded. This position could be identified either by markers (visual tags) or by tracking technologies such as GPS, sensors, infrared, or laser. (3) Scene processing: As the scene becomes clearly recognized and identified, the corresponding virtual content is requested, typically from the Internet or from any kind of database. (4) Scene visualization: Finally, the AR system produces a mixed image of the real space as well as the virtual content [6].

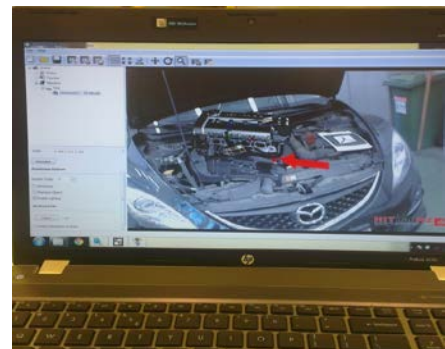
The application of AR for presenting models in 3D can be part of all areas of engineering where virtual three-dimensional models are used in the process of engineering design. Anyhow, the most common use of AR is in the areas of mechanical engineering, architecture and for the needs of the educational processes in engineering [5].



**Fig. 3** Visual instruction manual for vehicles maintenance in BMW (source: BMW AG).

One of the areas in which the use of AR is very common is the assembly procedures of machines and devices (Fig. 3). Instead of operators reading the operations sequence from fixed displays, which might result in fixed positions in an assembly line, augmented reality can be easily moved through the complete facility using a laptop, tablet or a smartphone. The most important that a good AR system offers to the industrial market is the connection with optical or mechanical sensors, like optical or mechanical measuring devices. In that way, users (operators) have the ability to transfer the acquired data at one post to the next and to superimpose them on the existing CAD drawings of the part augmenting the view of the user and providing valuable information at the right time.

Numerous companies from the automotive industry have developed and deployed solutions based on Augmented Reality. Toyota in partnership with the Copenhagen Institute for Interactive Design has developed a solution for entertainment of the backseat passengers. General Motors developed a concept for enhancing the driver's view of the road by placing virtual lines on the road edges helping the driver maintain the desired route in low visibility conditions. Mercedes has developed AR based applications for choosing the details like color, bumpers, alloy wheels and interior of their A-class and presenting a 3D model of the selection.



**Fig. 4** View of Augmented Reality based solution for acquiring data elements in the vehicle approval process.

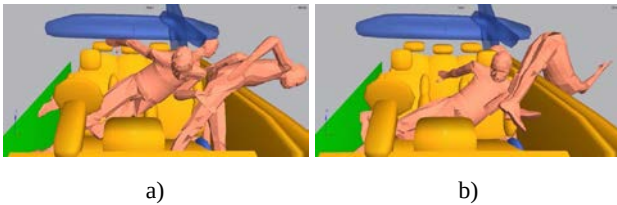
With the advancement of the software tools for design and development of AR solutions, the development process of such solutions is no more task for a complete R&D department of a big automotive companies. Nowadays, this is possible for a small team or even a single developer. The authors of this paper have developed a solution for a visual step-by-step solution for assisting the operators in the process of acquiring data element in the process of vehicle approval (Fig. 4). The implementation of the developed solution resulted in lowering the lead time of the operation [10].

### 3. Analysis of existing technical solutions for visualization of vehicles in the process of crash forensics

The technical solutions for visualization of vehicles in the process of crash forensics have not been fully adopted according the development of the software and hardware used in these visualization solutions. In the beginning, the use of technical solutions for visualization in the process of crash forensics was in line with the development of visualization solutions based on computer graphics and animation. The use of technical solutions based on 3D modelling and Virtual Reality in the process of crash forensics was lacking behind of the development of these technical solutions. This was mainly due to the fact that the learning curve required to master the technology was too long. The development of Augmented Reality as a visualization technology has progressed rapidly in the last 10 years. However, its use in the process of crash forensics is still very limited.

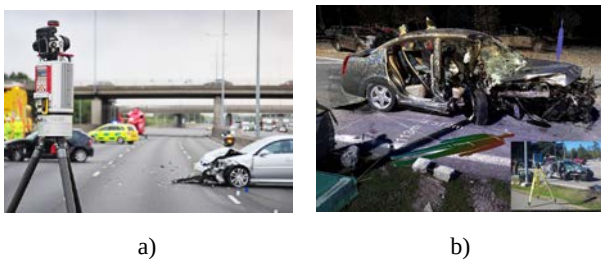
Other various technologies have supported the adoption progress of the visualization technologies in the forensics process. The use of CAD software that use dynamics simulation are one of

these technologies (Fig. 5). In the United Kingdom, computer records are acceptable as evidence if they can be proved to be correct and accurate [2]. This leads to the significance of introducing dynamic simulation (a.k.a. physically based simulation) to forensic animation, because dynamic simulation is capable of accurate modeling of objects and human motions based on Newton's laws of motion [1].



**Fig. 5** Computer Graphics Animation results from a CAD software using dynamics simulation to determine the motion of objects in an accident; a) what the perpetrator described, b) what the software simulate based on evidence and marks on the vehicle. (Source: Advanced Symtech; 2015).

One more very important technology that supported the adoption progress of the visualization technologies in the forensics process is the use of laser scanning (Fig. 6). The laser scanning devices offer the possibility to acquire a huge number of accurate measures from an accident scene providing the technicians with the ability to acquire the measures and leave the incident site very fast. After scanning the site, the acquired data are introduced to a CAD software in order to create a 3D model of the accident and complete the crash forensics process. The main barriers of this technology are the very high price of the laser scanning equipment, the accuracy and portability of the equipment and again the learning curve of the technicians for mastering this technique.



**Fig. 6** Laser Scanning of a crash site. a) Scanning an accident site, b) Measuring important distances using CAD software based on the data acquired by laser scanning. (Source: MAPTEK; 2016).

Vehicular accident reconstruction work often focuses on estimating the speeds of crashed vehicles. Vehicle velocities are often estimated by correlating the crush deformation of a crashed vehicle with vehicle speeds using stiffness coefficients determined from crash tests. Vehicle crush is determined by measuring the crashed vehicle and comparing these dimensions with a reference vehicle, the exemplar. Other methods include measuring the length of skid marks, vehicle displacement and other accident geometry [7].

Standard practice in most police departments today is to measure accident scenes and vehicle crush manually using calipers and tape measures. This is time-consuming, slow, sometimes dangerous and often limited to a few tens of measurements. Slow is a big problem in areas of congested traffic. Closing a lane to measure accident sites often leaves the driving public stuck in traffic, which can lead to collateral incidents. The police officer in charge at the scene sometimes has to make a tough call to balance the requirement to take sufficient measurements for evidence against minimizing disruption to the driving public [7].

#### 4. Possible technical solutions for visualization of vehicles in the process of crash forensics based on Augmented Reality

This paper presents the results of conducted research in the direction of use of technical solutions for visualization of vehicles in the process of crash forensics, presenting their positive characteristics along with their limitations. The focus of the research was to determine if the technical solutions for visualization based on AR and VR can help collecting the necessary data on faster, more precise and reliable way, and provide additional information valuable in the process of forensics.

The concept idea for use of AR based solution is to eliminate the use of expensive equipment and to foster the rising performances of the all present hand-held devices (smart phones and tablets). The mid and high-end range hand held devices are equipped with sufficient processing power along with sensors with satisfactory accuracy (GPS sensor, infrared, gyroscope etc.). This provides an opportunity to move the technical solutions for visualization of vehicles from laboratories to the actual incident scene and from the expensive equipment to the hand-held devices.

Using the software application for mobile devices Augment, the crash site reality can be augmented by adding a 3D CAD model of the same vehicle overlaying the crashed one as presented in Fig.3. This results in enriching the sight of an expert assisting him/her in visualization of the level of deformation on the crashed vehicle by comparing it to the original shape and dimensions of the same type of vehicle.

The application was tested using a real crashed vehicle and a CAD model of the same type acquired through the Google Warehouse database of 3D models. The next step was to adjust the CAD model by setting the correct scale of the model and the appropriate coordinate system. Next, the CAD model of the vehicle was uploaded to the servers of Augment in order to later use it in their application for hand-held devices. For the purpose of this research, as a test specimen a crashed vehicle available at a local dealership was selected. The specimen vehicle is moved from the original crash site and the front bumper is removed, but these parameters are considered to be not important for the goal of the test and that is to analyze the applicability of the solution. On a regular iPad tablet the Augment app was installed and logged in to the previously made account where the CAD model was uploaded. At the location of the crashed vehicle, the CAD model was loaded to the iPad. The back faced camera of the iPad displays the video feed of the crashed vehicle and its surrounding to the screen of the tablet. The previously loaded CAD model is overlaid on the real view of the crashed car resulting in an Augmented Reality as shown on Fig.7.

This tool should assist the expert in completing the crash forensics process easier and in higher accuracy right at the accident scene. By using the real crashed car and the real environment of the accident site this visualization technology results in lower costs. That is because these elements do not have to be modeled in CAD. In addition, this lowers the time needed to master the use of the technique. The downside on the software side of this solution is the need of a comprehensive data base of 3D models of different types of vehicles in order to use them as reference in the comparison. This can be solved in different ways, for instance by including the vehicles manufacturers by providing the 3D CAD models of their vehicles since they are already part of their production management

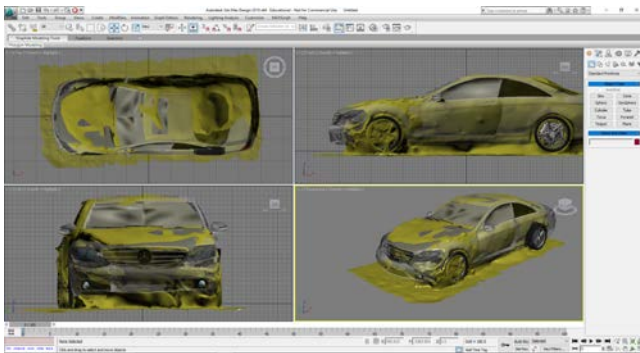
processes. The downside on the hardware side is the lack of ability to make measures using the software application, measuring for instance distances or angles between the real objects and the CAD model. The current generation of hand-held devices is not equipped with such sensors to measure depth. Nevertheless, this is the case of the devices used by general population. Already today on the market devices that have this technology incorporated exist, like Google's Project Tango, Structure's Sensor for iPad or Microsoft's Kinect.



**Fig. 7** Visual presentation of vehicles in the process of crash forensics using Augmented Reality.

### 5. Possible technical solutions for visualization of vehicles in the process of crash forensics based on Virtual Reality

The concept idea for use of VR based solution is to overcome the downside of the AR based solution for making measures in the process of crash forensics. Instead of using a high-end laser scanning equipment, this research investigates the possibilities of using a hand held scanning device – Google's Project Tango. This device, similar to its rivals, is equipped with a stereo camera (4 MP 2mm RGB-IR pixel sensor and 1 MP front facing with fixed focus), motion tracking camera with 3D depth sensing ability. This device incorporates all necessary sensors and processing capabilities under one chassis making it ideal for this application.

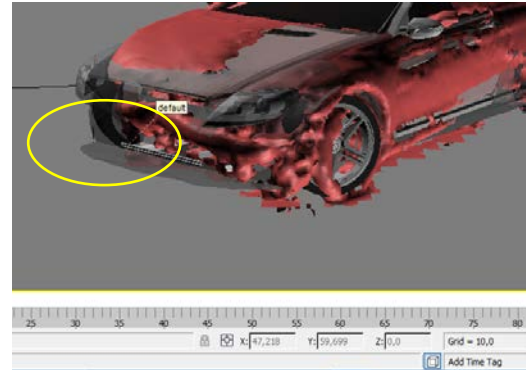


**Fig. 8** Visual presentation of vehicles in the process of crash forensics using Virtual Reality.

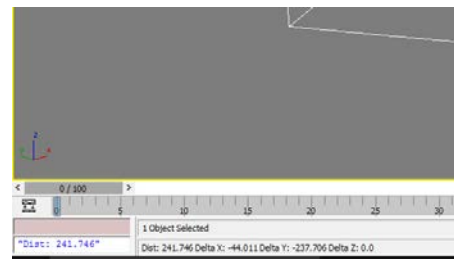
Using the Tango tablet the crashed vehicle is being scanned and a 3D CAD model is exported. The scan was done on the same specimen vehicle at a local dealership. The ability to export .OBJ file types provides the opportunity to use different types of software applications. For the purpose of this research the Autodesk's software 3ds Max was used. The .obj file from the scanned crashed vehicle is imported in 3ds Max and overlaid on the CAD model of the vehicle as presented in Fig. 8.

This provides the same visualization and comparing capabilities like the AR solution. In addition, this solution provides the ability to make accurate measures between the elements in the scene (distances and angles). Like presented in Fig. 9a, the displacement between two points can be easily and accurately measured. The displacement of a point from the CAD model of the vehicle and the same point selected from the crashed vehicle is presented by all three axes relative to a same Cartesian coordinate system. For the purpose of this research, related to the characteristics of the crash, as point of interest the front lateral beam of the chassis

understructure was selected. The tested VR solution provides the ability to measure the displacement according the x, y and z axes of all points of this element from its original position to its deformed position after the crash. This task is conducted in a form of a dialogue where after starting the command of the "Measure" tool, the software asks the user to select the first point by clicking on one of the models, then selecting the second point while presenting a dashed line between the two selections illustrating the measured distance. The result is presented on the command line (Fig.9 b.).



a)



b)

**Fig. 9** Visual Reality based solution's ability to make measures of distance between objects. a) Selecting points to measure distance; b) Displacement of the selected points by all three axes.

The main downside of such solution is the accuracy of the scanned crashed vehicle. The selected vehicle did not have significant damage, so the faces of its shape acquired with the Tango tablet were accurate enough and easy to recognize. But if the crashed vehicle has significant damage than the level of accuracy provided with this hardware is not going to be sufficient. Additional techniques can be introduced for improving the scan quality like use of markers, limiting the reflection of the surfaces and securing the adequate level of light.

### 6. Conclusions

The presented technical solutions for visualization of vehicles in the process of crash forensics based on Augmented Reality and Virtual Reality impose as possible additional tool for the experts. They are reliable and easy accessible, with short learning curve. At this point, they can be perceived as assistance to the process only if they are used by experienced forensics experts with broad understanding of vehicle dynamics and mechanics.

Further research and development in this field should move towards closing the loop – that is by using the data (measures) acquired through this solution to result in the end with assistance in calculating accurate information like speed and direction of moving of the vehicles, components of the acceleration, intensity and angle of the forces applied to an object, etc. This would make the presented solution much more usable and productive in the crash forensics process.

## 7. References

- [1] Minhua Ma; Huiru Zheng; Harjinder Lallie: Virtual Reality and 3D Animation in Forensic Visualization; J Forensic Sci, September 2010, Vol. 55, No. 5.
- [2] Burton AM, Schofield D, Goodwin LM: Gate of global perception: Forensic graphics for evidence presentation; Proceedings of the 13th Annual ACM International Conference on Multimedia; 2005 Nov 6–11; Singapore. New York, NY: Association for Computing Machinery, 2005; pg. 103–11.
- [3] Sutherland Ivan E.: A Head-Mounted Three-Dimensional Display; Harvard University, 1968.
- [4] Azuma R.: A Survey of Augmented Reality, Teleoperators and Virtual Environments, August 1997, USA, pp. 355–385.
- [5] Tashko Rizov, Elena Dimova Rizova: Augmented Reality As a Teaching Tool in Higher Education; International Journal of Cognitive Research in Science, Engineering and Education (IJCRSEE) Volume: 3 Issue: 1 Pages: 7-15, 2015.
- [6] DHL Customer Solutions & Innovation: Augmented Reality in Logistics – Changing the way we see logistics a DHL perspective; 2014.
- [7] Sean Higgins: Laser Scanning for Accident Reconstruction; SPAR 3D, 2004.
- [8] Petar Pejić, Tashko Rizov, Sonja Krasić, Risto Tashevski: Presentation of Existing Architectural Objects Using Augmented Reality: Case study - Ada Bridge, Belgrade, Serbia; South East European Journal of Architecture and Design Volume 2015; Article ID 10011, 2016.
- [9] Azuma R. T.; Predictive Tracking for Augmented Reality; Chapel Hill, North Carolina, USA: University of North Carolina, 1995.
- [10] T. Rizov: Geometrical Presentation of Objects in Interactive Augmented Reality; PhD dissertation; Faculty of Mechanical Engineering – Skopje; 2014.

# METHODOLOGY OF CARRYING RESEARCHES OF KINEMATIC PAIR OF PIVOTING FRICTION

Ph.D. Eng. Wozniak M.<sup>1</sup>, Ph.D. Eng. Kubiak P.<sup>1</sup>, Ph.D. Eng. Pluciennik P.<sup>1</sup>, M.Sc. Eng. Jozwiak P.<sup>1</sup>, Eng. Madziara S.<sup>1</sup>, Eng. Najbert S.<sup>1</sup>, Prof. M.Sc. Ozuna G.<sup>2</sup>, Eng. Gomez L.<sup>2</sup>, Ph.D. Eng. Chunbao L.<sup>3</sup>

Department of Vehicles and Fundamentals of Machine Design – Lodz University of Technology, Poland

Department of Industrial Engineering and Systems - University of Sonora, Mexico<sup>2</sup>

State Key Laboratory of Mechanical Transmission, Chongqing University, Chongqing, China<sup>3</sup>

marek.wozniak.1@p.lodz.pl, przemyslaw.kubiak@p.lodz.pl, jozwiak.piotr@gazeta.pl, 171243@edu.p.lodz.pl, 174616@edu.p.lodz.pl, gozuna@industrial.uson.mx,

**Abstract:** The paper presents the program and methodology of carrying out research on kinematic pair with pivoting friction. There was examined a node with pivoting friction in bearing concentrated connection flat surface-spherical bowl. During the research there were determined two types of characteristics – characteristic of friction moment as a function of load and experimentally designated characteristic of wear of the frictional kinematic pair. Both of the assigned characteristics are compared..

**Keywords:** MOMENT OF FRICTION, PIVOTING FRICTION, FRICTION COEFFICIENT, WEAR

## 1. Introduction

The phenomenon that occurs between two bodies in contact in rest or in motion is called friction. As a result of this phenomenon there arises resistance to motion. There are various kinds of friction distinguished (figure 1).

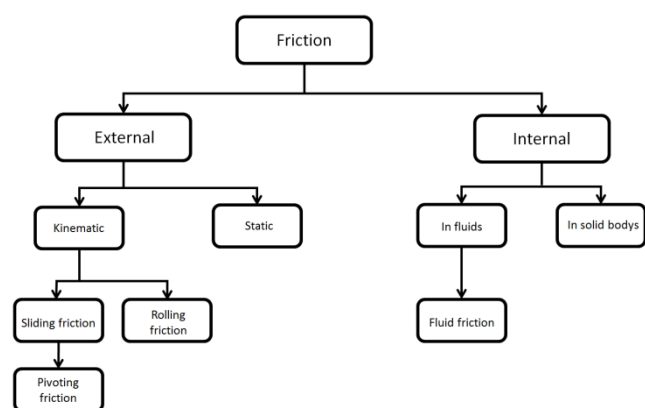


Fig. 1 Types of friction [4].

Machines constructors try to eliminate dry friction, replacing it with more advantageous fluid friction. Due to the fact that cooperating surfaces are not ideally smooth, on the top of the irregularities of the surface there could occur dry or boundary friction, whereas the cavities could be filled with lubricant. In such conditions the friction between the rough contact surfaces is so called mixed friction [2].

## 2. Pivoting friction

One particular case of sliding friction that occurs in slide bearings is pivoting friction, caused by continuous rotation or oscillation around the normal in point of contact between two cooperating surfaces. Pivoting friction occurs in the bearings: measuring timing devices, analogue scales, spindles, textile machinery etc. This paper attempts to analyze the conditions of pivoting friction for bearing model: flat surface - spherical bowl (figure 2). In this type of bearings obtaining fluid friction, even in case of total immersion of lubricating agent node (figure 3), is not possible due to the scattering of the gaps.

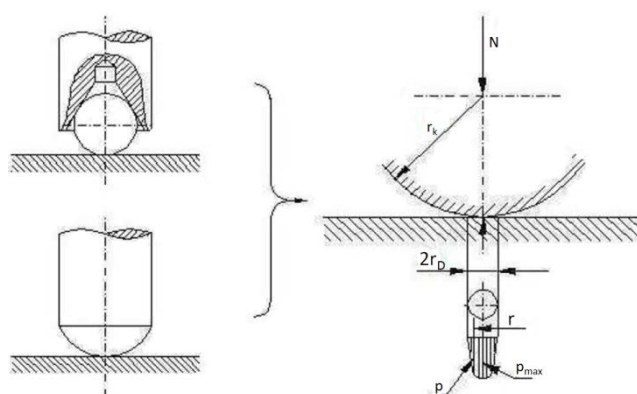


Fig. 2 Model of the bearing type spherical cap on plate;  $p$  - Hertz pressure,  $p_{max}$  - Hertz pressure maximum [3].

$$p_{max} = \frac{1}{\pi} \sqrt{\frac{6 \cdot N \cdot \frac{1}{r_k^2}}{\left( \frac{1-\nu_1^2}{E_1} + \frac{1-\nu_2^2}{E_2} \right)^2}} \quad (1)$$

where:  $\nu$  - Poisson ratio,  $E$  - Young's modulus,  $N$  - axial force,  $r_o$  - contact radius,  $r_k$  - sphere radius.

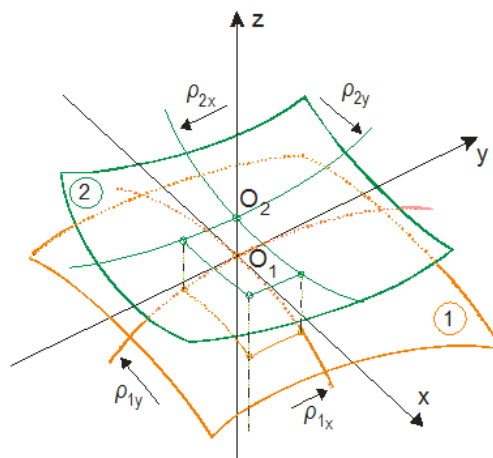


Fig. 3 General model of the slide bearing;  $r_1, r_2$  – curvature radius of mating surfaces [5].

### 3. Experimental research model

In the initial examination there was used a bearing ball made of steel 100Cr6 of diameter 8mm and a flat plate made of Ertalon. The test was performed only in conditions of dry friction, without the use of the lubricant.

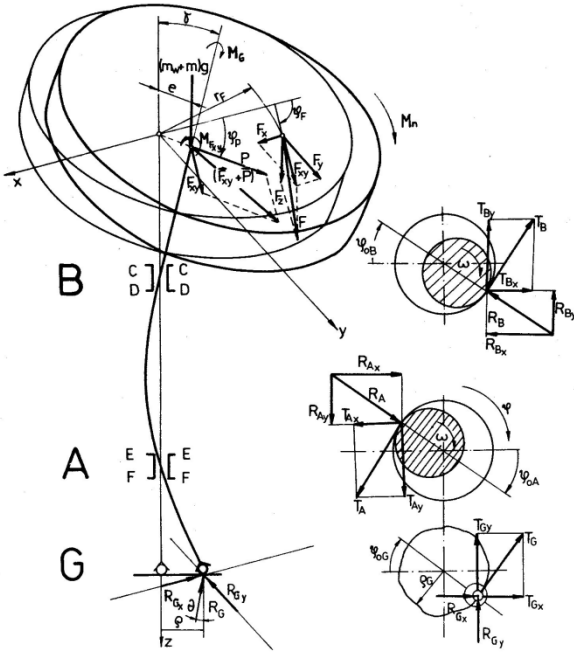


Fig. 4 Scheme of general model of radial thrust bearing [1].

### 4. Test bench

Figure 5 presents the test bench for determination of friction coefficient by the string twist angle measurement.

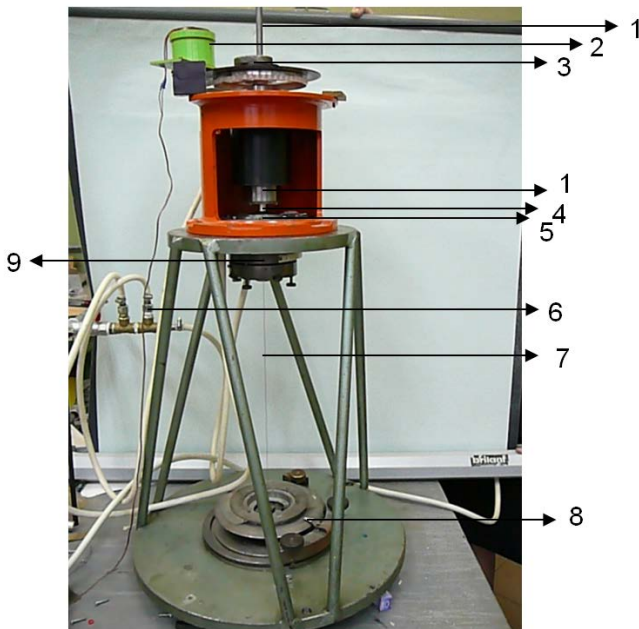


Fig. 5 Test bench for the friction moment and friction coefficient for the frictional pair ball joint – spherical cap; 1 – shaft, 2 – electric motor, 3 – weights, 4 – sphere, 5 – compressed air supply, 6 – string, 7 – disc to read the angle of torsion, 9 – aerostatic table [6].

The test bench is made of two cylindrical radial bearings and axial bearing. The drive from electric motor (2) is transferred by the belt transmission on the shaft (1) which is ended by the ball joint. The load is changed by adding weights (3) on the shaft (1). The

tested ball joint (5) is placed on the aerostatic table (9) which is connected with the string (7). The second end of string is mounted to the table (8) which is used to twist string angle compensation. The angle of compensation is read from the scale plotted on the table (8).

### 5. Test bench researches

For the initial experiment there were selected bearing balls made of steel H-15 (100Cr6) of diameter 8 mm and a flat plate made of Ertalon (PA6-E). Experimental measurements were carried out by measuring the moment of friction as a function of load. In addition, the test results calculated due to the varying string angle verified friction torque values designated with signs of wear on the plate.

The test bench research was performed by the measurement of the torsional angle of the string as a function of load. The electric motor was started after mounting the plate from PA6-E and steel ball (100Cr6) to the test bench. The shaft rotated with constant speed – 36 rpm. Then the test bench was gradually loaded by 2 N in the range 7,09÷16,9N. After that the test bench worked in the inverse sequence. Weights were added for 500 cycles.

The smallest load due to the weight of shaft was 7,09 N and peak load was the sum of the weight of the shaft and weights. Each measurement was repeated in 10 measuring series in order to calculate the average value of the string twist angle. The moment of friction was determined according to the relationship:

$$M_f = 33,722 \cdot \mu \cdot p_{\max} \cdot N \cdot r_k \cdot \left( \frac{1 - \nu_k^2}{E_k} + \frac{1 - \nu_p^2}{E_p} \right) \quad (2)$$

Track wear plate measuring scanned using an optical microscope with a mounted camera. Assuming that the diameter of the wear scar is  $2r_o$  friction torque calculated from the relationship:

$$M_f = 2 \cdot \pi \cdot \mu \cdot p_{\max} \cdot 7,1633 \cdot r_o^3 \quad (3)$$

### 6. Measurement results

Below is a sample list of friction torque for the combination of friction couple: plate from ertalon (PA6-E) – steel ball (100Cr6).

Tab. 1 Radius  $r_o$  of the wear traces on the plate in the function of load for the examined sample

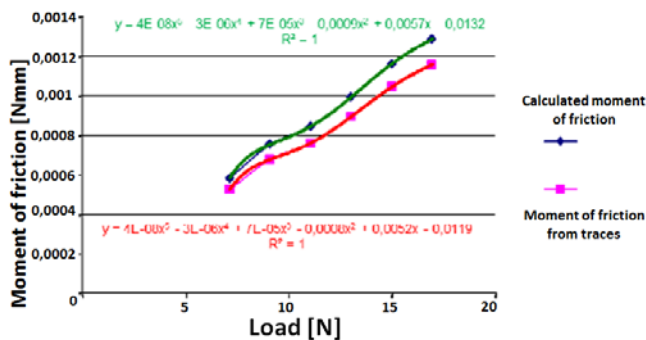
| $m_w$ [kg] | $m$ [kg] | $g$ [m·s <sup>-2</sup> ] | $d_k$ [m] | $\nu_k$ | $\nu_p$ | $E_k \cdot 10^6$ [Pa] | $E_p \cdot 10^6$ [Pa] | $r_o \cdot 10^5$ [m] |
|------------|----------|--------------------------|-----------|---------|---------|-----------------------|-----------------------|----------------------|
| 0,723      | 0,0      | 9,81                     | 0,008     | 0,308   | 0,298   | 210000                | 180000                | 5,71                 |
|            | 0,2      |                          |           |         |         |                       |                       | 6,19                 |
|            | 0,4      |                          |           |         |         |                       |                       | 6,61                 |
|            | 0,6      |                          |           |         |         |                       |                       | 6,98                 |
|            | 0,8      |                          |           |         |         |                       |                       | 7,32                 |
|            | 1,0      |                          |           |         |         |                       |                       | 7,63                 |

Tab.2 Analytical values and values from traces of wear determined for the friction moment of the frictional pair ertalon-steel.

| Load [N] | $p_{\max}$ [Pa] | Friction $\mu$ [-] | Average moment of friction [Nmm] | Average friction $\mu$ [-] | Moment of friction from trace [Nmm] |
|----------|-----------------|--------------------|----------------------------------|----------------------------|-------------------------------------|
| 7,09263  | 1,04 E+09       | 0,067029           | 0,00059                          | 0,067846                   | 0,00052487                          |
| 9,05463  | 1,13 E+09       | 0,062566           | 0,000721                         | 0,059811                   | 0,00067849                          |
| 11,01663 | 1,21 E+09       | 0,054026           | 0,000845                         | 0,053975                   | 0,00076099                          |
| 12,09786 | 1,27 E+09       | 0,051049           | 0,000994                         | 0,051049                   | 0,00089470                          |
| 14,94063 | 1,33 E+09       | 0,049443           | 0,001152                         | 0,049041                   | 0,00104548                          |
| 16,96541 | 1,39 E+09       | 0,046451           | 0,001286                         | 0,046451                   | 0,00115785                          |



**Fig. 6** Example trace of wear on the flat surface,  $r_o=0,258$  mm,  $S=0,209$  mm<sup>2</sup>.



**Fig. 7** Graph of moment of friction in function of load for the researches of friction couple PA6-100Cr6.

## 7. Summary

1. The moment of friction increases proportionally to the load.
2. The characteristic of the friction momentum as a function of load determined analytically is the same as the characteristic determined by the wear.
3. Differences in momentum of friction for analytical calculations and the values determined from the exploitation do not exceed 0,00012 Nmm in the entire load range.
4. The values determined analytically were calculated for the springy connection. The values of friction momentum determined from the wear include the impact of the plastic deformation and the exploitation.

## 5. References

1. Burcan J.: *Analiza oporów ruchu i jej wykorzystanie w projektowaniu drobnych mechanizmów precyzyjnych*, Politechnika Łódzka, Zeszyty Naukowe Nr 546, rozprawa habilitacyjna, Łódź, 1989,
2. Dietrich M.: *Podstawy konstrukcji maszyn*, Tom 2, WNT, Warszawa 1999,
3. Wozniak M., Ozuna G., De La Fuente P., Jozwiak P., Pawelski Z.: *Comparison of friction coefficient for selected car suspension elements*. International Virtual Journal for Science, Technics and Innovations for the Industry MTM. Year VIII, Issue 4/2014, pp.23-25, ISSN 1313-0226,
4. Lawrowski Z.: *Tribologia – Tarcie, Zużywanie i*

*Smarowanie*, Warszawa, PWN 1993,

5. Burcan J.: *Analiza oporów ruchu i jej wykorzystanie w projektowaniu drobnych mechanizmów precyzyjnych*. Zeszyty Naukowe nr. 546, Politechnika Łódzka, Łódź, 1989,
6. Wozniak M., Ozuna G., De La Fuente P., Jozwiak P., Pawelski Z.: *Comparison of researches of friction coefficient in concentrated contact for the stress: steel-steel and steel-magnesium alloys*. International Virtual Journal for Science, Technics and Innovations for the Industry MTM. Year VI, Issue 6/2013, pp.51-54, Bulgaria, 1-2.07.2013,

# THE NEW EXHAUST AFTERTREATMENT SYSTEM FOR REDUCING NO<sub>x</sub> EMISSIONS OF DIESEL ENGINES: LEAN NO<sub>x</sub> TRAP (LNT). A STUDY

PhD Student Eng. Vrabie V., Prof. Dr. Eng. Scarpete D., PhD Student Eng. Zbarcea O.  
"Dunărea de Jos" University of Galati, Romania

vlad.vrabie@ugal.ro

**Abstract:** In nowadays, reducing emissions of the nitrogen oxide (NO<sub>x</sub>) in diesel engines become a principal goal for the future. The new technology Lean NO<sub>x</sub> Trap (LNT, is also known like NO<sub>x</sub> adsorber catalyst (NAC) or NO<sub>x</sub> Storage and Reduction (NSR) catalyst) can be applied on passenger cars, light and heavy-duty diesel engines to reduce NO<sub>x</sub> emissions substantially. The NO<sub>x</sub> emissions are absorbed onto a catalyst during lean engine operation. After the catalyst is saturated, the system is regenerated in short periods of fuel rich operation during which NO<sub>x</sub> is catalytically reduced. This paper presents a literature review about the function and importance of LNT as the new aftertreatment exhaust system for reducing the NO<sub>x</sub> emissions of the new generation of diesel engines.

**Keywords:** EMISSIONS, NITROGEN OXIDE (NO<sub>x</sub>), DIESEL ENGINES, LEAN NO<sub>x</sub> TRAP (LNT), AFTERTREATMENT, EXHAUST SYSTEM

## 1. Introduction

Lean-burn engines provide more efficient fuel combustion and lower CO<sub>2</sub> emissions compared with traditional stoichiometric engines. However, the effective removal of NO<sub>x</sub> from lean exhaust represents a challenge to the automotive industry. In this context, lean NO<sub>x</sub> traps (LNTs), also known as NO<sub>x</sub> storage-reduction (NSR) catalysts, represent a promising technology, particularly for light duty diesel and gasoline lean-burn applications. Moreover, recent studies have shown that the performance of LNTs can be significantly improved by adding a selective catalytic reduction (SCR) catalyst in series downstream [1].

The lean NO<sub>x</sub> trap (LNT) technology is considered as one of the aftertreatment solutions to reduce NO<sub>x</sub> emissions from lean burn or diesel engines, those that operate under highly oxidizing conditions. Typically, LNT catalysts usually consisting of precious metals (e.g. Pt, Pd, Rh), a storage element (BaO) and a high surface area support material (e.g. Al<sub>2</sub>O<sub>3</sub>, CeO<sub>2</sub>, ZrO<sub>2</sub>), operate under transient conditions that include lean and rich phases. Pt material properties, including dispersion and particle size, are known to be important factors in determining NO<sub>x</sub> uptake performance, since Pt provides active sites for NO oxidation to NO<sub>2</sub> necessary for storing NO<sub>x</sub> as nitrates, and for the reduction of nitrates to N<sub>2</sub> [2].

LNT catalysts are typically composed of at least one precious-metal component and one alkali or alkaline-earth component which are supported on a high surface area refractory oxide. These catalysts operate in a cyclic manner, whereby the catalyst stores or "traps" NO<sub>x</sub> as nitrate species during lean period of operation. Periodically a short rich pulse is introduced so that the trapped NO<sub>x</sub> is released and reduced to N<sub>2</sub>, thereby regenerating the trapping capacity of the catalyst [3].

The LNT operates by storing NO<sub>x</sub> during normal lean operation (when excess oxygen in the exhaust hinders the chemical reduction of NO<sub>x</sub>). The LNT must be regenerated periodically by a rich excursion, a brief event in which the exhaust air/fuel ratio (AFR) is driven rich to achieve overall reducing conditions. The excess-fuel derived reductants (HCs, CO, H<sub>2</sub>) cause the release and subsequent reduction of the stored NO<sub>x</sub> [4].

Reducing emissions of the nitrogen oxide (NO<sub>x</sub>) in diesel engines become a main goal for the future, because it's needed to maintain the diesel engine as a propulsion source with highest fuel economy. Due to strict legislation, the automotive manufacturers are forced to adjust to the new requirements on exhaust emissions.

This paper presents the necessity and importance of the LNT catalyst for reducing the NO<sub>x</sub> emissions of the new generation of diesel engines. Also, this study wants to show the benefits of this new technology in combination with other catalytic systems.

## 2. Operating characteristics and performance

Under lean conditions, NO is oxidized to NO<sub>2</sub> in the gas phase over platinum. The resulting NO<sub>2</sub> is adsorbed on an oxide surface

as barium nitrate. Typical adsorbents include oxides of potassium, calcium, cerium, zirconium, lanthanum, calcium and barium. The sequence of steps is [5]:

Step I:  $\text{NO} + \frac{1}{2} \text{O}_2 \rightleftharpoons \text{NO}_2$

Step II:  $\text{BaCO}_3 + 2\text{NO}_2 \rightleftharpoons \text{Ba}(\text{NO}_3)_2$

At rich air fuel ratios, the adsorbed barium nitrate is released from the trap as barium oxide. In the presence of reducing agents such as CO, HC and H<sub>2</sub> and Pt/Rh catalyst, the NO<sub>x</sub> is converted to nitrogen and the trapping constituent, barium carbonate is restored. The sequence of steps is [5]:

Step III:  $\text{Ba}(\text{NO}_3)_2 \rightleftharpoons \text{BaO} + 2\text{NO}_2$

Step IV:  $2\text{NO}_2 + 2\text{CO/HC} \xrightarrow{\text{Pt/Rh}} \text{N}_2 + 2\text{CO}_2$

Step V:  $\text{BaO} + \text{CO}_2 \Rightarrow \text{BaCO}_3$

Sulfur present in the fuel acts as a poisoning agent. In the combustion process, the sulfur is oxidized to sulfur dioxide (SO<sub>2</sub>). The sulfur dioxide is oxidized to sulfur trioxide in the presence of platinum. The sulfur trioxide is trapped as barium sulfate at the trap operating conditions [5].

NO<sub>x</sub> adsorber technology removes NO<sub>x</sub> in a lean (i.e. oxygen rich) exhaust environment for diesel engines. The mechanism involves (see figure 1 and figure 2) [6]:

- Catalytically oxidizing NO to NO<sub>2</sub> over a precious metal catalyst;
- Storing NO<sub>2</sub> in an adjacent alkaline earth oxide trapping site as a nitrate;

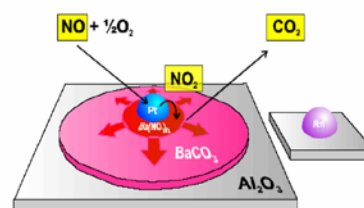


Fig. 1 The lean NO<sub>x</sub> trap running under lean conditions [6,7].

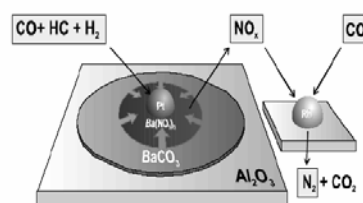


Fig. 2 The lean NO<sub>x</sub> trap running under period regeneration (rich) conditions [6,7].

- The stored  $\text{NO}_x$  is then periodically removed in a two-step regeneration step by temporarily inducing a rich exhaust condition followed by reduction to nitrogen by a conventional three-way catalyst reaction.

In order to reduce the trapped  $\text{NO}_x$  to nitrogen, called the  $\text{NO}_x$  regeneration cycle, the engine must be operated rich periodically for a short period of time (a few seconds). This cycling is also referred to as a lean/rich modulation. The rich running portion can be accomplished in a number of ways including [6]:

- Intake air throttling;
- Exhaust gas recirculation;
- Post combustion fuel injection in the cylinder;
- In-exhaust fuel injection;

It is likely to dominate for small diesel vehicles, such as passenger cars, at least in the near term, as it is a more cost effective solution for these vehicles than SCR. In a  $\text{NO}_x$  trap, a  $\text{NO}_x$  storage component, usually an alkali or alkaline earth metal oxide, e.g. barium oxide, is added to the platinum and rhodium catalyst. Under normal lean diesel conditions this stores  $\text{NO}_x$  as nitrate, but every 60-120 seconds or so the nitrate regenerates by running the engine with more fuel for a few seconds, so that some carbon monoxide and hydrocarbon can reduce the nitrate to harmless nitrogen [7].

In the scientific work [8], are presented the typical application, estimated cost per vehicle, the advantages and limitations of LNT system. As typical application are the light-duty vehicles with engine displacements below 2.0 liters. Cost 320 \$ for engines < 2.0 l and 509 \$ for displacement of engines > 2.0 l.

Advantages [8]:

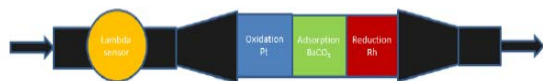
- 70-90% efficiency at low loads;
- Good durability and  $\text{NO}_x$  reduction performance;
- More economical for engines less than 2.0 l;
- No additional reductant tank is needed (lower packaging constraints);
- Reductant fluid not required (no refills needed).

Limitations [8]:

- $\text{NO}_x$  storage capacity is limited by physical size of LNT; Highway and uphill driving can overwhelm the capacity of LNT, leading to high  $\text{NO}_x$  emission events;
- For engines > 2.0 l, more frequent trap regeneration events are required, leading to additional fuel penalties (around 2%);
- Precious metal usage is high (approximately 10 to 12 g for a 2.0 l engine);
- $\text{NO}_x$  adsorbers also adsorb sulfur oxides resulting from the fuel sulfur content, and thus require fuels with a very low sulfur content (< 10 ppm). Sulfur compounds are more difficult to desorb, so the system has to periodically run a short “desulfation” cycle.

Application examples: VW Polo, VW Golf, BMW 2-Series [8].

The Lean  $\text{NO}_x$  Trap (Fig. 3) is also now known as a  $\text{NO}_x$  Storage Catalyst or  $\text{NO}_x$  Adsorber Catalyst [9]. It collects  $\text{NO}_x$  using compounds that form nitrates under stable conditions in lean operation.

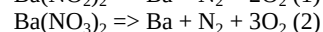


**Fig. 3** The lean  $\text{NO}_x$  trap [9].

The LNT was originally used on gasoline direct injection (GDI) engines which could switch between normal gasoline operation (at or around stoichiometric air/ fuel ratios) and lean mixtures. Any sulphur build-up is exhausted by running at an elevated temperature of between 600°C and 700°C. This is rather more easily achieved on gasoline engines which are able to run up to 900°C compared to the diesel engine's 700°C.

In a diesel engine use may be made of the very flexible “Common Rail” fuel system to create a “post” injection to effect the required temperature rise. An unwanted emission from the LNT is

that of ammonia. This requires an oxidation catalyst to keep within the European limit of 10 ppm at tailpipe. The reducing chemical equations are [9]:



For diesel LNTs the future challenge is to maximize  $\text{NO}_x$  conversion at low speed driving conditions as well as providing high  $\text{NO}_x$  conversion during high speed driving [10].

The Selective Catalytic Reduction (SCR) system is proposed as first choice for large vehicles which require high  $\text{NO}_x$  conversion efficiencies over high vehicle mileage (such as SUVs for US Tier 2 Bin 5 emission standards). The LNT technology is considered as an attractive alternative for smaller vehicles with lower  $\text{NO}_x$  reduction efficiency demand (e.g. for EU5 and post EU5 legislation) [11].

A major challenge in the future for LNT technology is desulfurization and thermal aging and thus the long-term stability. Conversely, system packaging in the vehicle including the required SCR catalyst, tank volume and the low temperature activity will be important issues to be solved for SCR technology [11].

A second considerable challenge remains, which is the issue of the infrastructure for the urea distribution, especially in the U.S. The concerns of the EPA regarding this technology remain and have to be addressed by each manufacturer that attempts to launch a diesel vehicle in the U.S. using SCR exhaust aftertreatment [11].

### 3. System combination between LNT and SCR

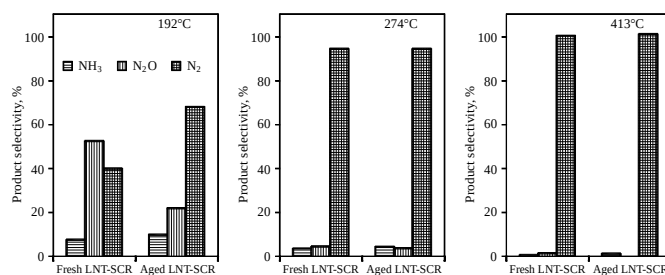
The removal of  $\text{NO}_x$  and particulate emissions in light-duty diesel vehicles will require the use of aftertreatment methods like Diesel Particulate Filters (DPF) and Selective Catalytic Reduction (SCR) with urea and Lean  $\text{NO}_x$  Trap (LNT). A new combination is between LNT and SCR, which enables on-board synthesis of ammonia ( $\text{NH}_3$ ), which reacts with  $\text{NO}_x$  on the SCR catalyst [12].

The SCR may utilize any  $\text{NH}_3$  emanating from the Lean  $\text{NO}_x$  system to eliminate further  $\text{NO}_x$  from the tailpipe. This has been used, for instance, on a Mercedes-Benz “Bluetec” vehicle system and may become a much more general approach as the diesel engine OEMs are faced with ever more stringent  $\text{NO}_x$  legislation [9].

In the case of the LNT/SCR dual bed, again the amounts of  $\text{NO}_x$  removed are lower at any temperature because of the inhibition of  $\text{CO}_2$  on the storage of  $\text{NO}_x$ . The  $\text{NO}_x$  removal efficiency is always higher for the hybrid LNT-SCR systems, both dual bed and physical mixture compared to single LNT, in the absence and in the presence of  $\text{CO}_2$  and  $\text{H}_2\text{O}$ . This is due to the contribution of  $\text{NO}_x$  stored onto the LNT catalyst and of  $\text{N}_2$  produced by the SCR reactions over the Fe-ZSM-5 catalyst during the lean phase. The presence of  $\text{CO}_2$  and  $\text{H}_2\text{O}$  reduces the  $\text{NO}_x$  removal efficiency over all the investigated systems [13].

J. Wang et al. have studied the effect of simulated road aging on the  $\text{NO}_x$  reduction performance of coupled Pt/Rh LNT and Cu-CHA SCR catalysts using  $\text{H}_2$ , CO and  $\text{C}_3\text{H}_6$  as  $\text{NO}_x$  reductants [14].

Figure 4 shows the product selectivity for the LNT catalyst and LNT-SCR systems using 2.5%  $\text{CO}$  as the reductant. As was the case for  $\text{H}_2$ , the selectivity of  $\text{NO}_x$  reduction to  $\text{NH}_3$  over the LNT is increased after aging. It is also noteworthy that after aging a decrease in the selectivity of  $\text{NO}_x$  reduction to  $\text{N}_2\text{O}$  over the LNT



**Fig. 4** Comparison of product selectivity over LNT catalyst and LNT-SCR system using 2.5%  $\text{H}_2$  as reductant; top: 192°C; middle: 274°C; bottom: 413°C [14].

catalyst is observed [14].

The selectivity to  $N_2O$  is high at 192°C for both the fresh and aged LNT when CO is used as the reductant, although the low  $NO_x$  conversion at this temperature limits the  $N_2O$  emission from the LNT in absolute terms. In general, the factors controlling the selectivity of  $NO_x$  reduction to  $N_2O$  are poorly understood, although catalyst composition appears to play a major role. The nature of the reductant has also been highlighted; however, published data are conflicting on the subject of which reductant affords the highest selectivity to  $N_2O$ . This is presumably a consequence of differences in the composition of the catalysts used in these studies, as well as the use of different reaction conditions [14].

In figure 5 [15] is presented a LNT-SCR system for  $NO_x$  reduction.

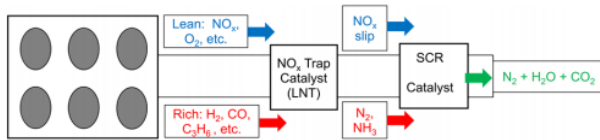


Fig. 5 Coupled LNT-SCR System for  $NO_x$  reduction [15].

The LNT-SCR system has several significant benefits in comparison with  $NO_x$  reduction technologies. Most importantly, the LNT-SCR system requires only fuel as the reductant and therefore eliminates the need and associated cost for the urea infrastructure. The LNT-SCR system also has several advantages over an LNT-only system. First, the SCR catalyst eliminates  $NH_3$  slip from the LNT by storing it and subsequently catalyzing its reaction with unreacted  $NO_x$  from the LNT. Second, the presence of the SCR catalyst relaxes the  $NO_x$  conversion requirements of the LNT. Consequently, the LNT catalyst volume in the LNT-SCR system can be lower than for an LNT only system, reducing the precious metal costs for the system. Third, the durability of the LNT-SCR should be superior since the system requires both less frequent and shorter desulfations than an LNT-only system owing to its higher overall efficiency and mitigation of  $H_2S$  emissions, respectively [15].

Figure 6 shows an SCR de $NO_x$  system in its most extensive layout. SCR systems for Euro 4 (requiring about 60%  $NO_x$  reduction) will generally not have the NO to  $NO_2$  catalysts. Also the hydrolysis catalyst is optional, since the SCR catalyst itself is very effective for hydrolysis. An  $NH_3$  clean-up catalyst may be applied as a safeguard measure. The urea dosage control will be open-loop with look-up tables for  $NO_x$  or urea quantity as a function of engine speed and load and catalyst temperature [16].

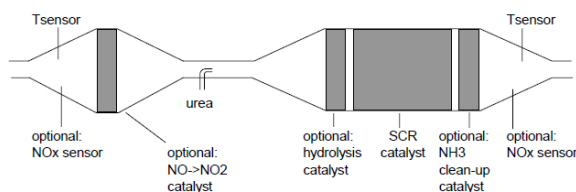


Fig. 6 Layout of urea SCR de $NO_x$  system [16].

Primary advantage of a closed-loop control strategy with a  $NO_x$  sensor is that urea dosage can be adapted to engine-out  $NO_x$  variations due to variations in ambient conditions and fuel quality [16].

Some key differences between EU and US  $NO_x$  technology control choices (e.g., the prevalence of LNT in Europe, and the emergence of combined SCR+LNT solutions in the US, likely because this type of solution is ultimately required for compliance with the low-emission bins of US Tier 2 regulations) seem to indicate that the different regulatory frameworks (the US has lower nominal emission limits, more demanding test cycles, and a robust enforcement and compliance program that the EU lacks) have a

direct influence upon the technological choices made by diesel passenger car manufacturers [8].

#### 4. System Combination Between LNT, SCR and DPF

Additionally a DPF (Diesel particle filter) may be added to the LNT+SCR system for treatment of particulates. DPFs will become necessary for Euro 6 and beyond as particulate number legislation has been introduced for Diesel and DISI Gasoline types [9].

The combination system between Lean  $NO_x$  Trap (LNT), Selective Catalytic Reduction (SCR) and Diesel Particulate Filter (DPF) catalysts, is shown in figure 7. Engine  $NO_x$  is reduced by the LNT and SCR catalysts. The LNT stores  $NO_x$  and undergoes controlled periodic regeneration, releasing the  $NO_x$  as nitrogen and ammonia. The SCR collects the released ammonia and uses it to continuously treat the remaining  $NO_x$ . A Diesel Particulate Filter (DPF) traps Particulate Matter (PM) and undergoes periodic regeneration [17].

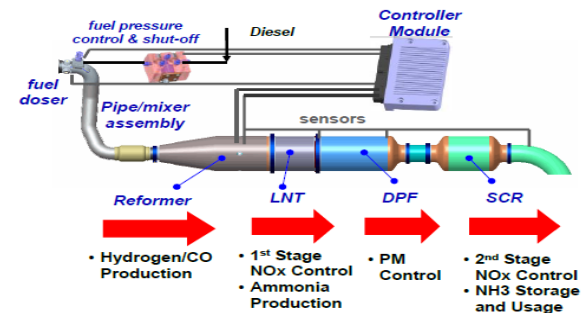


Fig. 7 Combination system between LNT, SCR and DPF [17].

#### 5. Conclusions

The lean  $NO_x$  trap (LNT) technology is considered as one of the aftertreatment solutions to reduce  $NO_x$  emissions from lean burn or diesel engines, those that operate under highly oxidizing conditions.

LNT catalysts are typically composed of at least one precious-metal component and one alkali or alkaline-earth component which are supported on a high surface area refractory oxide.

LNT catalysts usually consisting of precious metals (e.g. Pt, Pd, Rh), a storage element (BaO) and a high surface area support material (e.g.  $Al_2O_3$ ,  $CeO_2$ ,  $ZrO_2$ ), operate under transient conditions that include lean and rich phases.

$NO_x$  adsorber technology removes  $NO_x$  in a lean (i.e. oxygen rich) exhaust environment for diesel engines.

For diesel LNTs the future challenge is to maximize  $NO_x$  conversion at low speed driving conditions as well as providing high  $NO_x$  conversion during high speed driving.

The LNT technology is considered as an attractive alternative for smaller vehicles with lower  $NO_x$  reduction efficiency demand (e.g. for EU5 and post EU5 legislation).

A major challenge in the future for LNT technology is desulfurization and thermal aging and thus the long-term stability.

The SCR catalyst eliminates  $NH_3$  slip from the LNT by storing it and subsequently catalyzing its reaction with unreacted  $NO_x$  from the LNT.

The presence of the SCR catalyst relaxes the  $NO_x$  conversion requirements of the LNT. Consequently, the LNT catalyst volume in the LNT-SCR system can be lower than for an LNT only system, reducing the precious metal costs for the system.

The durability of the LNT-SCR should be superior since the system requires both less frequent and shorter desulfations than an LNT-only system owing to its higher overall efficiency and mitigation of  $H_2S$  emissions, respectively.

Further it's recommended more tests and experiments using catalyst systems combined LNT-SCR-DPF and LNT-SCR-DPF with Diesel Oxidation Catalyst (DOC), and the diesel engines tested to be fueled with alternative fuels, such as simple mixtures biodiesel-diesel (with different concentrations of biodiesel),

bidoiesel-in-diesel fuel emulsions and water-in-diesel fuel emulsions.

### Acknowledgements

The authors would like to acknowledge to the “Dunărea de Jos” University of Galați Romania for supporting this research and the paper publishing.

### References

- [1] Wang, J. et al. The effect of regeneration conditions on the selectivity of NO<sub>x</sub> reduction in a fully formulated lean NO<sub>x</sub> trap catalyst. *Catalysis Today* 175 (2011) 83–92.
- [2] Wang, X., et al. Effect of reductive treatments on Pt behavior and NO<sub>x</sub> storage in lean NO<sub>x</sub> trap catalysts. *Catalysis Today* 175 (2011) 78–82.
- [3] Wang, J., et al. NO<sub>x</sub> Reduction on fully formulated Lean NO<sub>x</sub> Trap catalysts subjected to simulated road aging: Insights from steady-state experiments. *Chinese Journal of Catalysis*, Volume 32, Issue 5, 2011.
- [4] West, B., et al. Assessing reductant chemistry during in-cylinder regeneration of diesel Lean NO<sub>x</sub> traps. 2004 SAE International.
- [5] Wang, Y., Raman, S., Grizzle, J.W. Dynamic modeling of a Lean NO<sub>x</sub> Trap for lean burn engine control. *Proceedings of the American Control Conference*, San Diego, USA, pages 1208-1212, 1999.
- [6] \*\*\*. Emission control technologies for diesel-powered vehicles. Manufacturers of Emission Controls Association, 1730 M Street, NW, Suite 206, Washington, D.C. 20036, December 2007 [www.meca.org](http://www.meca.org), [www.dieselretrofit.org](http://www.dieselretrofit.org).
- [7] [www.rsc.org/education/eic/issues/2011June/TheEvolutionOfCatalyticConverters.asp](http://www.rsc.org/education/eic/issues/2011June/TheEvolutionOfCatalyticConverters.asp).
- [8] Yang, L., et al. NO<sub>x</sub> control technologies for Euro 6 Diesel passenger cars. Market penetration and experimental performance assessment. White Paper, September 2015, 2015 International Council on Clean Transportation.
- [9] Lemon, D. Emission mitigation and control systems, Automotive exhaust emissions and energy recovery, 2014, ISBN 978-1-63321-493-4.
- [10] \*\*\*. Johnson Matthey, NO<sub>x</sub> Emissions Control for Euro 6. *Platinum Metals Rev.*, 2013, 57, (2), 157–159, <http://dx.doi.org/10.1595/147106713X663924>.
- [11] Schnitzler, J. FEV Motorentechnik GmbH, [http://www.fev.com/fileadmin/user\\_upload/Media/TechnicalPublications/Diesel\\_Systems/ParticulateMatterAndNOxExhaustAftertreatmentSystems.pdf](http://www.fev.com/fileadmin/user_upload/Media/TechnicalPublications/Diesel_Systems/ParticulateMatterAndNOxExhaustAftertreatmentSystems.pdf).
- [12] Maunula, T. Combination of LNT and SCR for NO<sub>x</sub> reduction in passenger car applications. *Combustion Engines* 2014, 157(2), 60-67, ISSN 2300-9896.
- [13] Castoldi, L., et al. Catalytic behaviour of hybrid LNT/SCR systems: Reactivity and in situ FTIR study. *Journal of Catalysis* 282 (2011) 128–144.
- [14] Wang, J. Effect of aging on NO<sub>x</sub> reduction in coupled LNT–SCR systems. *Journal of Catalysis* 282 (2011) 128–144.
- [15] \*\*\*. University of Kentucky for applied energy research. Development of optimal catalyst designs and operating strategies for Lean NO<sub>x</sub> reduction in coupled LNT-SCR Systems, BIOFUELS & ENVIRONMENTAL CATALYSIS, [http://www.caer.uky.edu/factsheets/biofuels\\_Fisk\\_LNT-SC10-8-09.pdf](http://www.caer.uky.edu/factsheets/biofuels_Fisk_LNT-SC10-8-09.pdf).
- [16] Rinie van Helden, et al. Optimization of Urea SCR deNO<sub>x</sub> systems for HD diesel engines. 2004 SAE International.
- [17] McCarthy, J. Fuel Reformer, LNT and SCR aftertreatment system meeting emissions useful life requirements. Corporation 2009 DOE DEER Conference Dearborn, MI August 5, 2009.

# METHOD OF PROJECTS IN THEORY LEARNING OF A FUTURE AGRICULTURAL ENGINEER

Candidate of Technical Sciences, Associate Professor Viktor Pryshliak

Ukraine, Vinnytsia National Agricultural University

[viktor.prishlyak@i.ua](mailto:viktor.prishlyak@i.ua)

**Summary.** New educational standards involve significant changes in the structure, content, aim and tasks of education. The article deals with the results of investigation of peculiarities of the method of projects usage in the theory of teaching a future agricultural engineer in higher education institutions. The method of projects in educational technologies provides solving an agricultural problem and it is directed into achieving a specific result that can be publicly presented and transferred to a customer. The main achievement is a creative research project that demands integrated knowledge, investigation for getting significant results of theoretical and cognitive character and practical character. Such project should be vital according to the chosen topic, problems and tasks, methods of investigation, sources of information, hypothesis and ways of solving the given problem.

**Keywords:** theory, training, method of project, activity, future agricultural engineer.

## ***Introduction.***

Competitiveness of an agricultural engineer at the labor market depends on the level of special basic education, fundamental knowledge, capacity for steady self-development, obtaining new competence, professional mastering of innovative technologies, adaptation to constant changes in agribusiness.

Domestic educational system responds to social and economic development tendencies and proposes European integrated conceptual ideas of competence oriented education. The economic development of society, increasing in material well-being of people are based on thorough and fundamental general science and special professional knowledge. To get this knowledge a future agricultural engineer expert should acquire to think creatively, cogitate pragmatic categories, and predict the result at the start-up period of implementing ideas and projects. Moreover, such an expert should be able to associate with colleagues, to work in team, to determine priorities, to plan a shop-floor activity, to bear personal responsibility for project implementation, to use computer equipment and information technologies effectively.

***Prerequisites and means for solving the problem.*** Using the method of projects in theory learning is of current importance because key competences of students are formed and pedagogical tasks are solved giving the opportunity: to learn how to plan a final result and a sequence of actions, to match future work with your potential, time management and economic factors, to use different sources independently, to find and use the right information, to solve problems constructively and to make own choices and decisions. Method of projects is a training system in which students obtain knowledge, skills and competence planning and doing the tasks that are becoming complicated gradually. The project is primarily a form of organization of activities aimed to obtain a specific product.

Project-based method allows bringing learning of students to solve practical and socially important tasks.

The term “method” is understood as the logic basis for mode of actions to consciously achieve the intended purpose under circumstance [1].

A work on a project is a logical continuation of profound study of a material. It requires from students to activate various psychological processes such as memory, imagination, and creative thinking. All work aimed on stimulating independent research activities should be formed gradually. Each student's creative work oversees primarily positive emotions and a feeling of being a pioneer or a researcher.

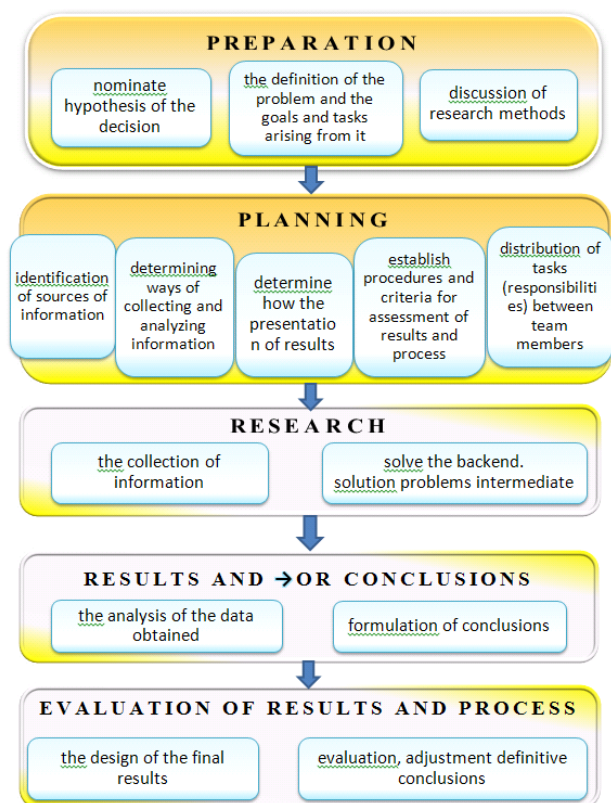
Introducing the pragmatic creative projects into the educational process makes students become interested in the final result of their activity, implementing these results into real farming.

The work on a project starts with the designing the project itself. Compulsory determinant factor of each project is an investigation a student does. The main stages of the project activity are preparation, planning, investigation, receiving and valuation the results, conclusions, and recommendations (Figure 1).

So, a project is passing through all the stages in a consecutive order: determining the problem, planning, designing itself, methodology and algorithms choosing, modeling, estimation and parameter optimization, getting the product (machine, process, technology, etc.), results documenting, illustration designing and its defense, report and working paper execution, and data transfer to a client.

***Solution of the examined problem.*** There are several levels of independent thinking of the technical specialties students in agricultural higher institutions: the first one corresponds with the teaching; the second one is the level of a problem setting by a

teacher and solving the situation together with the students; the third level foresees a student to solve the problem autonomously; the fourth affirms the absolute independence of a student who determines and solves the problem on his/her own.



**Figure 1.** The Main Stages of a Project Activity

Educational agricultural engineer projects are characterized by research, creative, role, live-action, information, applied and other typological features, the number of participants, and the terms of the development, etc.

Research projects require well thought-out structure, clearly determined aims, the relevance of the subject of the investigation, economic and social importance, specific theoretical and experimental methods of investigation, and data processing. They are conducted according to the common logical scheme and their structure is close to classic scientific researches.

The general criteria of a student preparedness to work on projects are existence of project type of thinking, the capacity to work in team, performing discipline, strong motivation to participate in a project, high entrepreneurial and social activity, flexibility and capacity to correct one's actions and decisions.

So far, the Standards of Education and the Statute of Ukraine "About Higher Education" declared the realignment of teaching. It is required not just to learn knowledge, capacity and skills, but to develop a personality, his/her talents, and independence of his/her thinking. Research and project work facilitates key competences of students; it takes participants of educational process into real farming out from the walls of the University. Method of

projects allows solving the following pedagogical tasks: to teach planning succession of actions, to foresee final results, to match future work with one's potential, time management and economic factors. The project is primarily a form of organization of activities aimed to obtain a specific product. Project-based method allows bringing teaching students to solve practical and socially important tasks. Implementation of projects allows making students more interested in a final result of an activity. A work on a project is a logical continuation of profound study of a material. It requires from students to activate various psychological processes such as memory, imagination, and creative thinking. Different and sometimes even new styles of communication could be possible in this case. It is important to figure out assumptions, options, and hypothesis for students and discuss them in the classroom. The main purpose of a teacher is to create conditions for development of a personality, self-determination and self-realization. It is important to guide students to generalization, to learn not only to solve problems of analysis and synthesis but also to use these concepts as an instrument of cognition.

Projects are divided into individual and group (complex) projects. Individual projects are characterized by the following peculiarities: a program and a plan of the project are made out in consideration of student's concern in the project result; it develops student's individual responsibility and professional competence. Figure 2 represents the scheme of personal project that completes the main course program [2]. It shows the level of student's skills that facilitate effective activity after getting specific knowledge.



**Figure 2.** The Level of Skills Development

Group projects help to form cooperative skills and thoroughly fulfill the project. In the formation of project activities development of rules for a group work is significant. Each student should feel wanted in the project, able to express his creativity completely and all-around. However, it is not recommended to

demand absolute silence organizing group work because students should exchange their opinion. You should not expect immediate results, and everything should be done in a proper way. It is not necessary to switch to a more complex work until you will learn simple forms of communication, discussion, and solution of specific project agronomic problems. Interacting in a group, students understand that all participants should come to an agreement in order to achieve a common goal. It is important to find the ideal relationship between both students and teachers. It is better to implement the method of projects with students together, listening to them attentively. The project activity on the faculty of agriculture mechanization is conducted from the first course to the last one. A project on planting of bioenergy crops on sloping lands has been written with a group of students.

Group activity is socially oriented.

On the basis of requirements for students' activity in a group, designed by I. Kolesnikova and M. Horchakova-Sybirska, the rules of cooperation were determined. As the scholars say, unconstrained joining to the project and emotional attitude towards the project are indicators of a student's readiness for a project work. While working on the project it is of special importance to consider the activity of both participants and those who are interested in a project development. To raise the quality of a project it's recommended to get qualified experts, teachers, scholars and representatives of agricultural units to join the project [3].

Here are some forbidden items in a group work organization:

- one should not require absolute silence, as students must share their thoughts;
- one should not expect immediate results; everything is digested practically;
- It is not necessary to switch to a more complicated tasks until simple forms of communication aren't learnt.

Interacting in a group students understand that all participants should come to an agreement in order to achieve a common goal. It is important to find the ideal relationship between both students and teachers.

Students of the Faculty of Agricultural Engineering work on projects from the first year to the last. Thus, first-year students under the supervision of teachers developed a project "Optimization of Agricultural Implements Complex for Crofts and Farming". Students got acquainted with structure, management and conditions of agricultural machinery storage. Studying harvester threshers there were held conferences and students presented their projects "Peculiarities of Mechanization of Grain Crops Harvesting Under the Conditions of Native Land". Students themselves made the plan to achieve results, selected materials, worked on supplementary literature and represented their achievements to other students.

Teachers provided the students with consultative advice, explained principles how to accumulate innovative information and its processing, and gave actual representing of final product for public speaking.

The third-year students developed the project on preparation of the field and bioenergetic crops sowing on the lands of a little gradient of slopes. The project represents general problems that are important for actual agro-industry [4]. Students worked on the certain elements of considerable problem, they used initial data and scientific achievements of their teachers in the process of working on course and qualification projects and thesis. Moreover, students investigated changes of agrochemical characteristics of soil alongside generatrix slopes that are typical for the region of their residence, peculiarities of functioning mechanical and technical means for sowing bioenergetics crops, represented the techno-economic feasibility of manufacturing process accomplishment.

**Results and discussion.** The output data of the project is further used by the senior students at the course «Machine Utilization in the Plant Growing Sector» while working on the course and graduation projects. Research project skills are formed gradually. A project develops mental processes during obtaining academic disciplines. Individual educational projects are compulsory in the training curriculum for future experts in agricultural engineering.

**Conclusion.** New educational standards causes significant changes in the structure, content, aims and tasks of education. Teaching process is provided according to the training curriculum for agriculture engineers. A student is supposed to be oriented on the general research way, be well-educated in the algorithm that helps to solve the given tasks, and manage the process of training activity on his own. One of the ways to make a student a subject of teaching process is to involve him into research project activity as an important didactic way that responds on updated needs of life. It is also supposed a successful student to be a successful agricultural engineer in future who designs and implements innovative projects. Agriculture, 2012. – Vol. 14, No6, 179-182.

## References

1. Dietrich J. Design and Construction: A systematic approach / Trans. with Pol. – M.: Mir, 1981. – 456.
2. Bendera I.M. The theory and method of independent work of future specialists in agricultural mechanization in higher education: Dis. ... Dr. ped. Sciences: 13.00.04 – K., 2008. – 579.
3. Kolesnikova I.A., Gorchakova-Sibirska M.P. Pedagogical designing. – Moscow: Academy, 2007. – 288.
4. Pryshliak Viktor. Technological and technical bases of sowing biopower cultures on the hill land of small steepness / MOTROL: Motoryzacja i energetyka rolnictwa, Motorization and energetics in agriculture, An international journal on operation of farm and agri-food industry machinery. – Lublin–Rzesów: Mot. and Energ. Rol., Commission of Motorization and Energetic in Agriculture, 2012. – Vol. 14, No 6, 179-182.