

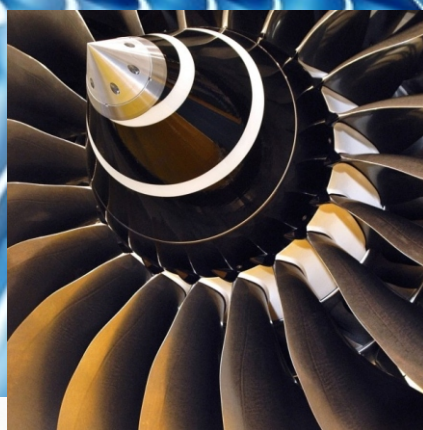
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OBJECTIFICATION AND DETERMINATION OF HAND-ARM VIBRATIONS

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Abstract: The paper is devoted to objectification and determination of the influence of hand-arm vibrations with selected machinery. We permanently meet with vibrations, but especially when performing work activities. When working with machinery, a person is constantly exposed to vibrations and they can very negatively affect the health of the person. The aim of the paper is to compare measured vibration values with the manual of the device and then to determine the maximum time exposure for work activities to avoid the employee being at risk of working with the device. Comparison of a final hand-arm vibration will be assessed by means of the hand-arm exposure calculator and software for a specific measuring device - vibration analyzer of the 4447 type. The proposed method - an extended risk matrix - is used to assess the risks of hand-arm vibration.

Keywords: VIBRATIONS, SAFETY, OCCUPATIONAL HEALTH PROTECTION

1. Introduction

Many work activities require regular and frequent use of vibrating tools and equipment. The handling of vibrating materials is also widely found in industries and provision of services. It is, for example, civil engineering, building of roads and railways, maintenance and improvement of real estate (maintenance of terrain, parks, watercourses, roads and their adjacent green belts), production of concrete products, forestry, foundry, heavy engineering, mining and surface mining, production and repair of automobiles, supply services to the public (works for water management companies, gas companies, power plants and telecommunication companies), building and repair of ships and other.

When in contact with work equipment and mechanical tools, a person is often exposed to shocks and vibrations that are harmful to human health when exceeding certain values. Vibrations increase the fatigue of a person because a large amount of muscle is trying to capture their effects. Damages caused by vibrations are dependent on amplitude, frequency, acceleration, and vibration count. They are caused in particular by chainsaws, drills, pneumatic hammers - locally transmitted vibrations (hand-arm vibrations), vibrating machines where the worker is sitting or standing - tractors, mobile machines - whole body vibration, special transmission - carried on the back. (OSHA, 2011)

2. Health risks associated with hand-arm vibration exposure

Some hand tools produce high vibration acceleration levels that can cause permanent damage to the hands and arms. This risk is caused by the Hand-Arm Vibration Syndrome (HAVS) syndrome which depends on the following factors:

- position and method of gripping tools,
- the length of time interval of work activity with tools,
- heat and cold load in the working environment,
- vibration level.

Exposure to hand-arm vibration syndrome could cause serious health-damaging effects, circulatory disorders, such as vibration white finger (VWF), sensitivity of the senses impairment, muscle, bone and joint damage. The second and more serious manifestation of the disease is the so-called Raynaud's syndrome, vibration white finger disease may occur at frequencies between 5-2,000 Hz, but the greatest risk is between 5-150 Hz. (OSHA, 2011)

3. Legal framework of the European Union related to factors at work

Measurement, objectification, and assessment of vibrations must firstly be in line with the applicable procedures and proposals that are underpinned by relevant valid binding legislation. The main legislative aspects used for the measurement and assessment of

hand-arm vibrations for which the different methods of exposure determination are as follows:

- Council Directive 2002/44/EC of 25 June 2002 on the minimum health and safety requirements regarding the exposure of workers to the risks arising from physical agents (vibration).
- ISO 5349 - 1:2001 Mechanical vibration - Measurement and evaluation of human exposure to hand-transmitted vibration - Part 1: General requirements.
- ISO 5349 - 2:2001 Mechanical vibration - Measurement and evaluation of human exposure to hand-transmitted vibration - Part 2: Practical guidance for measurement at the workplace.

This legislation sets out the limit and action values of vibration that can not be exceeded during the work performed. It contains methods for measuring and calculating the normalized vibration acceleration by means of which representative vibration values are obtained and then compared with the permissible values. This will also include assignment to the appropriate category of work. Table 1 lists the respective action and limit values of hand-arm vibrations. (Directive 2002/44/ EEC)

Table 1: Action and limit values for hand-arm-system

Transmission of vibration to the hands	
Resulting standardized acceleration a_{a}	$a_{\text{hv},8h} \text{ [m/s}^2\text{]}$
Limit value $[a_{\text{hv},8h,L}]$	5
Action value $[a_{\text{hv},8h,a}]$	2.5
Equivalent acceleration a_{b}	$a_{\text{veq},a} \text{ [m/s}^2\text{]}$
Action value – acting less than 20 minutes	12.25
Action value – acting less than 120 minutes	-
Notes:	
a) Equivalent weighted acceleration recalculated in terms of the normalized duration of work shift $T_n=8h$.	
b) Effective acceleration value determined at time T .	

4. Material and methods

Risk assessment procedure according to "Non-binding guide to good practice with a view of implementation of Directive 2002/44/ EC (Vibrations at Work) issued by the European Commission (EC) in 2009 is described in detail below.

The factors that govern the daily exposure of a person to vibrations are the frequency weighted vibration force (level) and the time of exposure of the person to this vibrational force. The greater the force is or the longer the exposure lasts, the greater the exposure of the person to the vibrations is.

The whole process can be modeled on the example of manual grinding of metallic material - performed irregularly during the work shift - profession of a locksmith.

To assess the threat rate, a representative sample value of 75% of the instruments was selected, i.e., acceleration

$$a_{hv} = 7 \text{ m/s}^2 \quad (1)$$

The estimation of daily vibration exposure $A(8)$ can be based on observation based on real work activities undertaken, i.e., on max. length of exposure to vibrations transmitted to the worker's hand and arm (Hand-arm vibration exposure calculator, 2012), for example,:

- grinding and cutting with an electric angle grinder with maximum duration 1 hour and duration 10 min.

Using the daily exposure estimation diagram $A(8)$ - Fig. 1, it is possible to determine the values for grinding and cutting on the apparatus under consideration, i.e.:

- grinding (7 m/s^2 per 60 min.): $A1(8) = 2.5 \text{ m/s}^2$
- cutting (7 m/s^2 per 10 min.): $A2(8) = 0.5 \text{ m/s}^2$

Total exposure to vibration will be evaluated by relationship:

$$A(8) = (A1(8)^2 + A2(8)^2)^{1/2} \quad (2)$$

i.e. after entering

$$A(8) = (2.5^2 + 0.5^2)^{1/2} = (6.25 + 0.25)^{1/2} = 2.55 \text{ m/s}^2 \quad (3)$$

When comparing graph limits, this calculated value of the total vibration exposure resulting from the activity under consideration is just above the action value of 2.55 m/s^2 , i.e., still within an acceptable range but indicating the need for taking measures.

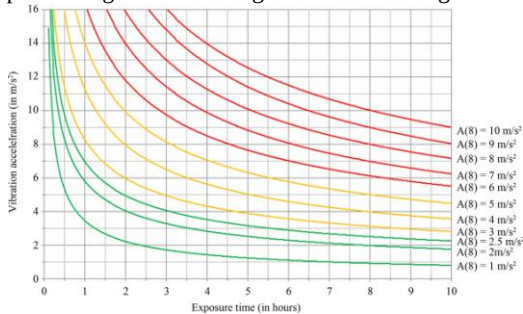


Fig. 1 Daily vibration exposure diagram according to EC Handbook

The rate of acceptability of the risk of exposure to vibrations:

- $A(8) < 2.5 \text{ m/s}^2$. The daily exposure to vibrations is lower than the level during activity. There is no need to take special measures to reduce exposure.
- $A(8) = 2.5 - 5.0 \text{ m/s}^2$. Daily vibration exceeds the level during level. For users, there is an increased risk of the disease caused by vibrations. Apply the manufacturer's recommendations and the measures mentioned in Directive 2002/44 / EC to reduce the risk of mechanical vibration.
- $A(8) > 5.0 \text{ m/s}^2$. Daily exposure to vibration exceeds the exposure limit values. Shorten your daily working time or use a machine with a lower equivalent vibration level.

The analyse and evaluate, the type 4447 hand-arm vibration analyzer also includes appropriate software. A vibration sensor and apparatus that is attached to it measures the vibrations stored in the analyzer and can be transmitted to the computer and evaluated using the software. The software evaluates and shows how many hours a person can work with the device to avoid vibration values being exceeded when operating with the device. (B&K)

5. Analysis and experiment evaluation

The aim of the experimental measurement was to assess whether the indicated values of the transmission of vibration to the hand and arm in the operating instructions comply with the legislative requirements of Directive 2002/44/EEC. The hand-arm vibration transmission measurement was performed using a 4447 vibration analyzer. The instrument meets the technical requirements of EN ISO 8041 and allows measurement according to the following standards:

- ISO 5349 Hand-arm vibrations,
- ISO 2631 Whole-body vibrations.

Vibrations were measured on three selected devices that were used in selected work activities where measured vibrations were evaluated and it was determined whether the values were exceeded according to the standard and according to the relevant operating instructions being a part of each device.

Vibration values (measured and values mentioned in the operating instructions) were compared and analyzed by the following methods:

- by software that is a part of the 4447 vibration analyzer,
- by freely available hand-arm vibration evaluation calculator developed by the Health and Safety Executive (HSE), also subject to Directive 2002/44/EEC.

Measurement No. 1: Jigsaw

The jigsaw is used to cut wood. With special knives, it is also possible to cut steel, plastic or aluminum.

Specifications of the jigsaw are recorded in Table 2.

Table 2: Specifications of the device – jigsaw

Performance	Number of strokes	Length of stroke	Inclined position	Weight
550 W	31 000min ⁻¹	26 mm	45° on both sides	2.4 kg

Table 3 shows the values recorded in the manuals as well as the values obtained by measuring the vibrations by the analyzer from the device during activity - wood cutting.

Table 3: Vibration values in manuals and vibration analyzer 4447 - jigsaw

Activity	Vibration value in the device manuals	Vibration value measured by vibration analyzer 4447 at time exposures		
		A(1)	A(4)	A(8)
Wood cutting	7.0 m/s ²	0.741 m/s ²	1.482 m/s ²	2.096 m/s ²

Vibration measurement on the machinery was performed using vibration analyzer 4447 according to ISO 5349-1: 2001 (ISO 5349-1:2001). The vibration sensor was located on the device's handle. By means of the device, sawing of 2 cm thick wood was carried out. (ISO 5349-2: 2001).

During measurement of vibrations, the limit and action values of vibrations were not exceeded. The measured vibration values obtained from the vibration analyzer match with the HSE hand-arm vibration exposure calculator aimed to evaluation of the hand-arm vibration. Values from activities performed by means of the machine device at time exposure $A(1)$, i.e., 0.714 m/s^2 and even $A(4)$, i. 1.482 m/s^2 were minimum and did not exceed the set and allowed values. Measured vibration values at 8 hour exposure were 2.096 m/s^2 . With this machine device it is possible to work 8 hours or more because the vibrations should not be exceeded.

By means of the HSE hand-arm vibration exposure calculator, it is possible to compare and find out whether the values in the exposures fall within and do not exceed the action and limit value of vibrations, and also determine how long it is possible to work with the machine in order not to exceed the action and limit values. In this case, on the HSE Calculator (EC Handbook, 2009) (Fig. 2), that the values with this device are not exceeded and meet the action and limit values of the vibrations for a given time exposure. From the measured values, it has been found that with this device, it is possible to work without problems even 8 hours or more.

According to the value mentioned in the operating instructions, it is possible to work with the work equipment for only 1 hour and 1 minute so that the accelerating action is not exceeded and 4 hours and 5 minutes in order not to exceed the limit value.

Fig. 2: Measured values when working with a jigsaw

Measurement No.2: Angle grinder

This device is designed for cutting, planing metal or even stone materials without the need for water. A special protection cover can also be used when cutting. This machine can also be used for grinding with grinding paper. The device specifications can be found in Table 4.

Table 4: Specifications of the device – angle grinder

Weight	Maximum diameter of grinding disc	Rated power input	Rated rpm
1.7 kg	115 mm	701 W	11 000 min ⁻¹

The vibrations on this machine were measured with a vibration analyzer using a tri-axis sensor. Vibration measurement on the device was done during iron grinding.

Table 5: Vibration values in manuals and vibration analyzer 4447 when grinding with an angle grinder

Activity	Vibration value in the device manual	Vibration value measured by vibration analyzer 4447 at time exposures		
		A(1)	A(4)	A(8)
Iron grinding	8.0 m/s ²	1.459 m/s ²	2.918 m/s ²	4.127 m/s ²

The measured vibration value at exposure of 1 hour A(1) was 1.459 m/s². The vibration value at exposure of 4 hours A(4) was 2.918 m/s², it means that the vibration action value, which is 2.5 m/s², was exceeded.

Upon these values, it can be stated that the worker can work with this device for 2 hours and 56 minutes to avoid exceeding the values.

At the vibration value measured for the 8 hour A(8) time exposure is 4.127 m/s² which exceeds the action value

Fig. 3: Measured values when working with an angle grinder

According to the operating instructions, it is only possible to work with the work equipment for 47 minutes, so that the acceleration action value is not exceeded and 3 hours and 8 minutes to avoid exceeding the limit value.

Measurement No.3 : Impact drill

The impact drill is used for drilling in various types of materials. It can be drilled in wood, iron, concrete or steel. The device specifications are listed in Table 6.

Table 6: Specifications of the device – impact drill

Weight	Performance	Idle speed	Without impact	Maximum chuck capacity
1.6 kg	701 W	0-2800 min ⁻¹	0-47600 min ⁻¹	13 mm

We obtained the measured vibration by means of a hand vibration analyzer 4447 on the machinery, i.e., an impact drill.

Table 7: Vibration values in a handbook and according to vibration analyzer 4447 for drilling in wood with impact

Activity	Vibration value in the device manual	Vibration value measured by vibration analyzer 4447 at time exposures		
		A(1)	A(4)	A(8)
Drilling in wood with the impact	25.3 m/s ²	1.673 m/s ²	3.347 m/s ²	4.734 m/s ²

The value of vibrations at an hour work A(1) was measured as 1.673 m/s². The value did not exceed either the action or limit value.

The value of four-hour A(4) vibrations was 3.347 m/s², and the worker can only work 2 hours and 13 minutes at this value to avoid exceeding the values according to the standard.

At work lasting eight hours A(8), the value of vibrations was 4.734 m/s², exceeding the limit value.

The measured data in the above mentioned three time exposures can be reassessed using the HSE hand-arm vibration calculator. According to the calculator, the employee can work for 8 hours without exceeding the HSE limit value (Handbook EC, 2009), Fig. 4.

Fig. 4: Measured values when working with an impact drill

According to the operating instructions, it is possible to work with the work equipment only 5 minutes in order not to exceed the acceleration action value and 19 minutes in order not to exceed the limit value.

Suggestion of a method for estimation of a risk of hand-arm vibration

For management of risk of vibration transmission, by harmonizing the risks of exposure to vibrations, it is possible to apply a standard matrix of risks, e.g. with use of parameters of period of exposure E (duration of exposure), probability of health hazard caused by exposure to vibrations resulting from work activities P and impacts D , see the Tab. 8. (Pačaiová, 2014)

Table 8: Suggestion of a method for estimation of risk of hand-arm vibrations (Pačaiová, 2014)

Impact (D)	Risk value (E+P) x D			Risk management
1 – slight damage	2 to 3	4 to 6	8 to 10	2 – 6 low risk, if $A(8) < 2.5 \text{ m/s}^2$, no measures are needed
2 – serious damage	4 to 6	8 to 10	12 to 15	8 – 10 medium risk, if $A(8) = 2.5 - 5.0 \text{ m/s}^2$, it is necessary to take technical or organizational measures a
3 – very serious damage	8 to 10	12 to 5	15 to 18	10 – 18 high risk, if $A(8) > 5.0 \text{ m/s}^2$, it is necessary to take immediate measures
	1 – unlikely	2 – possible	3 – sure	Probability (P)
	1 – short-term (up to 20 min.)	2 – average (from 20 to 60 min.)	3 – long-term	Exposure (E)

Table 9 shows the vibration values mentioned in the operating instructions as well as the vibration values measured by the vibration analyzer. At recalculation to an 8-hour exposure, a freely available HSE calculator was used. The values mentioned in the operating instructions were recalculated to show how long it is possible to work with the equipment in question so that the vibration action or limit values given in the applicable legislation are not exceeded. Subsequently, the table in the third column shows the longest possible exposure with the device when calculated with the values mentioned in the operating instructions. Based on the results, it can be stated that the measured values are much lower than those mentioned in the operating instruction for the device. According to the measured values, the vibration action values would be exceeded only in case of working with an impact drill so it is possible to work with this device max. 4 hours to avoid health damage.

The proposed method, based on Directive 89/391/EEC, was also used to assess the risk of hand-arm vibration. (Directive 89/391/EEC) Based on the assessment, it is possible to conclude that the high risk is in the case of working with an angle grinder as well as with an impact drill if the vibration value mentioned in the operating instructions applies. Damage to the upper limbs due to vibration may occur in these cases even if the time exposure is not exceeded.

Table 9: Application of the method for estimating the risk of the hand-arm vibration

Device	$a_{v,T} \text{ (m/s}^2\text{)}$	Action value $[a_{hv,8h,a}]$ Limit value $[a_{hv,8h,L}]$	Exposure	Probability	Impact	Risk
Jigsaw (wood sawing)	7 (in the operating instructions)	1 hour 1 minute	2	2	3	12
		4 hours 5 minutes				
	2.096 (measured values)	Limit and action values not exceeded	3	2	2	10

Angle grinder (iron grinding)	8 (in the operating instructions)	47 minutes	2	3	3	15
		3 hours 8 minutes				
	4.127 (measured values)	Limit value exceeded	3	2	2	10
Impact drill (drilling in wood with impact)	25.3 (in the operating instructions)	5 minutes	2	3	3	15
		19 minutes				
	4.734 (measured values)	Limit value exceeded	3	2	2	10

Conclusion

There are several recommendations for minimizing the harmful effects of vibration on the hand-arm system, while effectively combining them according to the type of work:

- replacing hand tools with a type that has a lower vibration level, allowing rest breaks, work device cycling, wearing warm gloves when working in cold environments or anti-vibration gloves, regular tool maintenance, training staff not to hold hand tools too firmly, advise workers to increase blood flow through repeated hand and finger exercises, education of workers and foremen regarding vibration hazard and encouraging them to report signals and symptoms of hand-arm vibration syndrome (HAVS).

According to the first recommendation, the use of tools with reduced vibrations is the appropriate measure. The problem of excessive vibration is widespread in most industrial plants using hand tools and tools. Excessive vibration interferes to a great extent with the working and living environment of the human being, thus affecting his/her health, physical and mental well-being. Legislation could also be more aware that by targeting vibration exposed workplaces and by thoroughly training workers using hand tools and tools during their working change, many negative effects of excessive vibration would be avoided.

An article was elaborated within VEGA 1/0121/18 Development of methods for implementing and verifying a comprehensive security solution in Smart Factory as part of Industry Strategy 4.0

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APPROACH OF CALCULATING THE AUTOMOTIVE GASOLINE INJECTOR ELECTROMAGNETIC PARAMETERS

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Abstract: The electromagnetic fuel injectors automotive are the gasoline injection systems main elements. The injectors perform the gasoline injection and its time of open condition, i.e injection duration determines the fuel quantity per working cycle [1]. The injectors are activated by solenoid and inject the gasoline in the engine manifold at the system pressure [2]. The gasoline injectors ensure precise fuel metering according to engine work state. The injectors are controlled by control signals, whose parameters are defined by the engine management system. The control devices are power transistors (drivers) in the electronic control unit (ECU). The injectors synchronizing and speed activating has a special significance and influence upon the increasing of the power and efficiency and the decreasing of the harmful emissions of the automotive engines. The synchronization of the electromagnetic gasoline injectors is connected by one hand of the injection according engine work order and by the other – with equal fuel injection duration and injection quantity. Meanwhile the injectors work at such conditions, which imposed constant compensation and adaptation activities by the ECU. This circumstance is connected with requirements of speed activating, which is measured by indicators, such as minimal electromagnetic activating force and minimal opening and closing time. This paper is considered the method of calculating the electromagnetic parameters of the automotive electromagnetic gasoline injectors for manifold gasoline injection.

Keywords: AUTOMOTIVE, INJECTOR, PARAMETERS, INJECTION

1. Introduction

A general layout of a typical automobile electromagnetic gasoline injector is shown in Fig.1.

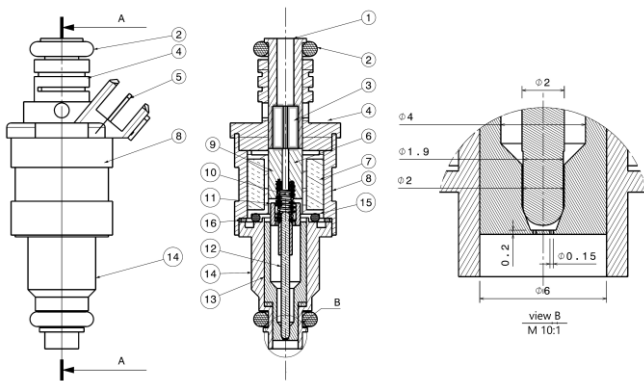


Fig.1. General layout of a typical automobile electromagnetic gasoline injector: 1-Inlet port; 2-O-ring; 3-Filter; 4-Cover; 5-Terminal; 6-Coil holder; 7-Coil; 8-Upper Housing; 9-Armature; 10-Spring; 11-Guide; 12-Needle; 13-Camera; 14-Lower Housing; 15-Internal O-ring; 16-Spacer Washer

The fuel inlet port 1 and the lower housing 14 are sealed with O-rings 2, respectively, to the fuel rail and the manifold. The filter 3 is located immediately after the inlet port in the cover 4. The cover is provided with a housing for accommodating the electrical terminals 5 connected to the winding 7 located on the coil holder 6. The upper housing 8 together with the lower housing closes the magnetic circuit. The housings are made of steel with corresponding strength, electromagnetic and anti-corrosion properties.

Upon feeding the control signal, the armature 9 draws the guide 11 and the associated needle 12 by collapsing the spring 10 and the fuel passing through the injector interior and the open seat of the chamber 13 is injected through two holes $\phi 0.15$ mm. When the signal is interrupted, the spring returns the needle to the starting position, whereby the needle seals the seat in the chamber with its front head and interrupts fuel injection through the spraying holes. Excess fuel that is at a higher pressure returns to the fuel rack. The positioning and sealing between the upper and lower housing is via the spacer washer 16 and the inner O-ring 15.

The ECU driver [2,5] (most commonly the Motronic system) actuates the injector control signal (Fig. 2, diagram a). The current in the winding of the electromagnet increases (diagram b) and this

leads to the needle lifting (diagram c). The maximum lift (full stroke) of the needle is achieved after t_{pk} (pickup time) [2]. The fuel is injected as soon as the needle starts to rise from the sealing seat. The total amount of injected fuel for one injection varies according to the characteristic shown in diagram d.

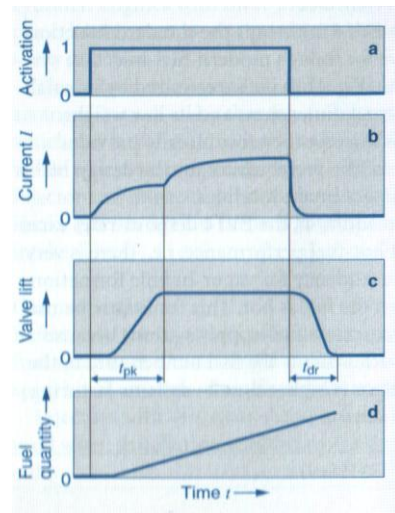


Fig.2. [2] Activation characteristics: a-trigger signal; b-current through the winding; c-stroke of the needle; d-quantity of fuel injected

The current through the winding decreases to zero when the control signal is terminated. The inertia of the moving parts (guide, needle, spring) causes the injector to close but with some delay. The injector closes completely after t_{dr} (drop-out time) [2]. When the injector is fully open, the amount of spraying fuel is proportional to time. The non-linear part of the injector opening and closing characteristic (t_{pk} and t_{dr} times) must be compensated for the entire injector actuation period (injection time t_{inj} , injection duration). The speed at which the needle is lifted also depends on the battery voltage.

A stainless steel is used to produce metal elements that come in contact with the fuel (i.e. gasoline) to ensure stable operation of the nozzle [2].

2. Approach

The force P with which the electromagnet attracts the guide and a related needle is determined by the formula [3]:

$$(1) \quad P = \frac{4(IW)^2 S}{\delta^2} 10^{-5}, \text{ g},$$

where: IW is the number of amper-turns;

S – the cross section of the magnetic core, mm^2 ;

δ – the distance between the guide and the core (armature stroke), mm .

At a set force P , formula (1) is usually converted to determine the required number of amper-turns:

$$(2) \quad IW = 50\delta \sqrt{10 \frac{P}{S}}.$$

The cross section S of the automotive injectors is assumed to be the cross section of the injector housing that closes the magnetic circuit. The optimal value of S can be approximated by the expression:

$$(3) \quad S = \frac{P}{10}, \text{ mm}^2.$$

It can be seen from (3) that the cross section S is optimal, whereby every square millimeter weighs 10 grams force of gravity.

After determination of the amper-turns IW to obtain the force P , at the given working current I and voltage U , the number of windings of the coil and its resistance R can be calculated:

$$(4) \quad n = \frac{(IW)}{i},$$

$$(5) \quad R = \frac{U}{i}, \Omega.$$

According to the laws of theoretical electrical engineering [4], the current through the winding is changed by the formula:

$$(6) \quad i = \frac{U}{R} \left(1 - e^{-\frac{R}{L}t} \right), \text{ A},$$

where: L is the inductance of the winding, H ;

t – time, s .

The inductance L is related to the number of the turns of the coil by the formula:

$$(7) \quad n = K\sqrt{L},$$

where: K is a coefficient depending on the core material.

The coefficient K is taken from tables or nomograms [3]. Inductiveness can also be determined empirically by methodology in the special literature.

To obtain the power in Newtons, formula (1) is converted, according to a second law of Newton:

$$(8) \quad P = \frac{4(IW)^2 S}{\delta^2} 10^{-2} \text{ g}, \text{ N},$$

where: g is the earth acceleration, m/s^2 .

3. Results

As a base model of the calculations an automotive electromagnetic injector is used, the scheme of which is shown in Fig.3.

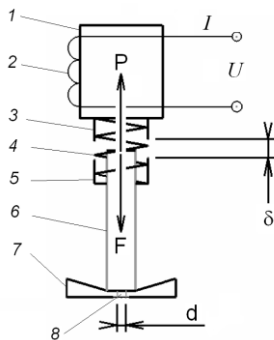


Fig.3. Calculation scheme: 1-electromagnet; 2-winding; 3-armature; 4-spring; 5-guide; 6-needle; 7-housing; 8-injection hole; d-diameter of the injection hole; δ - stroke of the needle

The electromagnetic parameters of the injector are presented in Table 1 together with the basic mechanical and hydraulic parameters.

According to the above-mentioned dependencies calculations were made for the determination of the electromagnetic parameters, taking into account the influence of the voltage of the battery at the start of the engine. The minimum, nominal and maximum values of the voltage ($U_{\min}$, U_n , $U_{\max}$), the current ($I_{\min}$, I_n , $I_{\max}$) and the electromagnetic force ($P_{\min}$, P_n , $P_{\max}$) are given in Table 1.

Table 1: Calculation parameters

Parameter	Design.	Dim.	Value		
Electromagnetic Parameters					
Operating Voltage	U	V	U_{min}	U_n	U_{max}
			9,00	14,20	15,40
Operating Current	I	A	I_{min}	I_n	I_{max}
			0,612	0,966	1,048
Resistance	R	Ω	14,7		
Inductance	L	H	0,060		
Coil Turns	n		1000		
Needle Stroke	δ	mm	1,00		
Electromagnetic Force	P	N	P_{min}	P_n	P_{max}
			25,97	64,70	76,15
Mechanical Parameters					
Needle Mass	m_n	g	0,7191		
Guide Mass	m_g	g	1,000		
Spring Mass	m_s	g	0,2151		
Injection Hole Diameter	d	mm	0,15		
Injection Hole Number	m		2		
Spring Force	F	N	10		
Hydraulic Parameters					
Fuel Type			Gasoline A, B, C [7]		
Работно налягане на горивото	$p_{гориво}$	bar	1,5 – 4,5		
Плътност на горивото (25 ⁰ C)	$\rho_{гориво}$	g/cm ³	0,719		

The calculation results for the electromagnetic force P in dependence on the stroke of the needle δ are given in Table 2. Table 3 gives computational results for the electromagnetic force P according to time t .

Figure 4 shows the change in working current I , A.

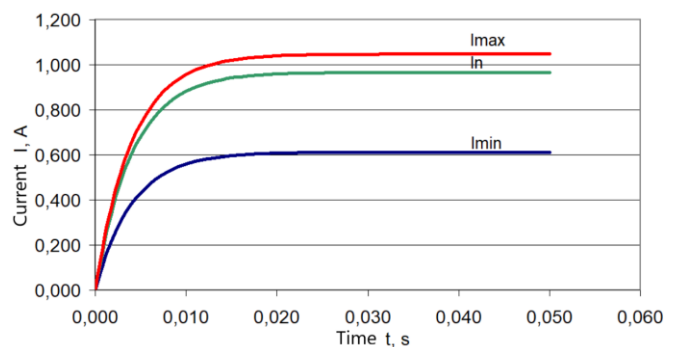


Fig.4. Operating current characteristics

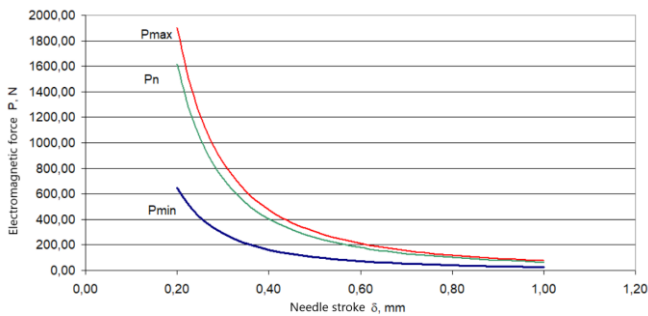
The value of the electromagnetic force P for the three voltage values is calculated with a fully closed needle or maximum needle stroke, i.e. at $\delta = 1,00$ mm. This is done in order to determine a force reserve for propelling the needle.

The maximum current value is reached for about $t = 0.015$ s, which applies to all three characteristics.

Table 2. Calculation results for electromagnetic force P depending on the stroke δ of the needle

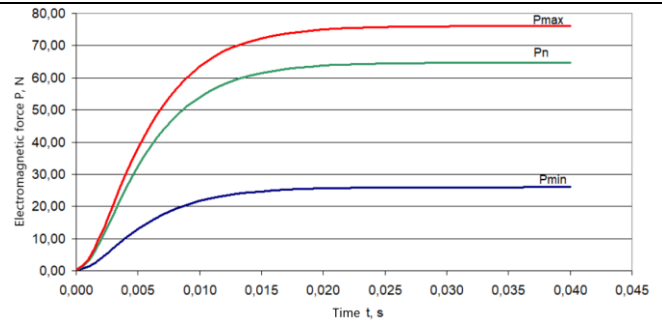
δ , mm	P , N	P_{min} , N	P_n , N	P_{max} , N
1	57,42	25,97	64,7	76,15
0,98	59,79	27,04	67,37	79,29
0,96	62,3	28,18	70,21	82,63
0,94	64,98	29,39	73,23	86,19
0,92	67,84	30,68	76,44	89,97
0,9	70,89	32,06	79,88	94,02
0,88	74,15	33,54	83,55	98,34
0,86	77,63	35,11	87,48	102,97
0,84	81,37	36,81	91,7	107,93
0,82	85,39	38,62	96,23	113,26
0,8	89,72	40,58	101,1	118,99
0,78	94,38	42,69	106,35	125,17
0,76	99,41	44,96	112,02	131,84
0,74	104,85	47,42	118,16	139,07
0,72	110,76	50,1	124,81	146,9
0,7	117,18	53	132,05	155,41
0,68	124,17	56,16	139,93	164,69
0,66	131,81	59,62	148,54	174,82
0,64	140,18	63,4	157,96	185,92
0,62	149,37	67,56	168,32	198,11
0,6	159,49	72,14	179,73	211,54
0,58	170,68	77,2	192,34	226,38
0,56	183,09	82,81	206,32	242,84
0,54	196,91	89,06	221,89	261,16
0,52	212,34	96,04	239,28	281,63
0,5	229,67	103,88	258,81	304,61
0,48	249,21	112,72	280,83	330,53
0,46	271,35	122,73	305,78	359,89
0,44	296,58	134,14	334,21	393,35
0,42	325,5	147,22	366,79	431,71
0,4	358,86	162,31	404,39	475,96
0,38	397,63	179,85	448,08	527,38
0,36	443,04	200,38	499,25	587,6
0,34	496,7	224,65	559,71	658,76
0,32	560,72	253,61	631,86	743,68
0,3	637,98	288,55	718,91	846,15
0,28	732,37	331,25	825,28	971,34
0,26	849,38	384,17	957,13	1126,53
0,24	996,84	450,86	1123,3	1322,1
0,22	1186,32	536,57	1336,82	1573,41
0,2	1435,45	649,24	1617,56	1903,83
0,18	1772,16	801,54	1996,98	2350,41
0,16	2242,89	1014,44	2527,43	2974,73
0,14	2929,49	1324,99	3301,14	3885,37
0,12	3987,36	1803,46	4493,22	5288,42
0,1	5741,8	2596,98	6470,23	7615,32
0,08	8971,57	4057,78	10109,74	11898,94
0,06	15949,45	7213,83	17972,86	21153,66
0,04	35886,27	16231,12	40438,95	47595,75
0,02	143545,09	64924,47	161755,78	190382,98
0	#####	#####	#####	#####

At the beginning of the opening of the needle and the reduction of the gap δ , the electromagnetic force P increases by exponential law and theoretically bends to infinity at $\delta = 0,00$ mm (fully open needle) - fig.5.

**Fig.5.** Characteristics of electromagnetic force depending on the gap (needle stroke)

The time to reach the maximum value of electromagnetic force is shown in Figure 6. The maximum value of electromagnetic force is reached for a time equal to that of the operating current, and has the same nature of increase.

In this way, the specific value of the electromagnetic force P can be determined for a particular interval and a period of time, as well as determining the time t_{min} to reach the required minimum value of the electromagnetic force P_{min} for the opening of the needle. Further it may be aligned with the frequency mode of the engine and hence be recorded in the control algorithm of the management system.

**Fig.6.** Characteristics of electromagnetic force depending on the time in a fixed gap**Table 3.** Calculation results for electromagnetic force depending on the time

δ , mm	P_{min} , N	P_n , N	P_{max} , N	t , s
1	0	0	0	0
1	1,23	3,05	3,59	0,001
1	3,9	9,71	11,42	0,002
1	7,04	17,53	20,62	0,003
1	10,14	25,25	29,7	0,004
1	12,96	32,27	37,96	0,005
1	15,41	38,37	45,13	0,006
1	17,48	43,51	51,17	0,007
1	19,18	47,76	56,17	0,008
1	20,58	51,22	60,24	0,009
1	21,7	54,02	63,53	0,01
1	22,6	56,26	66,17	0,011
1	23,32	58,04	68,26	0,012
1	23,88	59,46	69,93	0,013
1	24,33	60,58	71,25	0,014
1	24,69	61,46	72,29	0,015
1	24,97	62,16	73,11	0,016
1	25,19	62,71	73,75	0,017
1	25,36	63,14	74,26	0,018
1	25,5	63,48	74,66	0,019
1	25,6	63,74	74,97	0,02
1	25,69	63,95	75,21	0,021
1	25,75	64,11	75,41	0,022
1	25,81	64,24	75,56	0,023
1	25,85	64,34	75,67	0,024
1	25,88	64,42	75,77	0,025
1	25,9	64,48	75,84	0,026
1	25,92	64,53	75,89	0,027
1	25,94	64,56	75,94	0,028
1	25,95	64,59	75,97	0,029
1	25,96	64,62	76	0,03
1	25,96	64,64	76,02	0,031
1	25,97	64,65	76,04	0,032
1	25,97	64,66	76,05	0,033
1	25,98	64,67	76,06	0,034
1	25,98	64,68	76,07	0,035
1	25,98	64,68	76,08	0,036
1	25,98	64,69	76,08	0,037
1	25,99	64,69	76,08	0,038
1	25,99	64,69	76,09	0,039
1	25,99	64,69	76,09	0,04

4. Parameters evaluation

It is of the utmost importance that the injector provides the required cyclic fuel quantity at the right time and with the exact predetermined angle of advance of the injection. In other words, the performance of the injector defined by the minimum electromagnetic force P_{min} and the minimum trigger time t_{min} [5]. The minimum electromagnetic force is defined in the previous section. The minimum trigger time is related to the needle movement rate and is determined by the following dependencies.

The needle motion is determined by:

$$(9) \quad V_{n_i} = \frac{P_{i-1} - F}{m_n} \Delta t + V_{n_{i-1}}, \text{ m/s,}$$

where: Δt – time interval for needle motion, s;

V_{n_i} – needle speed at i interval, m/s.

The distance X traveled by the needle is determined of:

$$(10) X_{n_i} = \frac{P_{i-1} - F}{m_n} \Delta t^2 + V_{i-1} \Delta t + X_{n_{i-1}}, \text{ m,}$$

where: X_{n_i} - distance traveled by the needle at i interval, m.

After replacing the values for the electromagnetic and spring force and the needle mass, values of time t are set, the minimum time t_{min} being defined as corresponding to that of $X_n > 0$ mm.

The calculated minimum trigger time t_{min} is compared to actual oscillograms of the injector operation along with the electronic control unit of the engine test bench. Oscillograms were taken when the engine was started (Fig.7), idle (Fig.8) and acceleration (Fig.9).

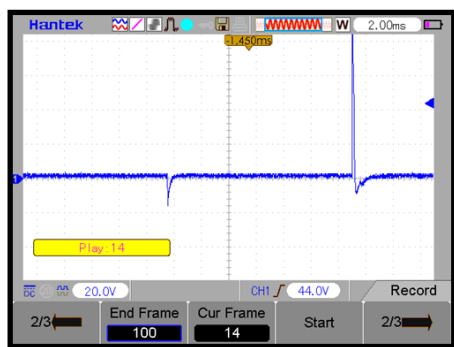


Fig.7. Oscillogram of the injector control signal at the engine start

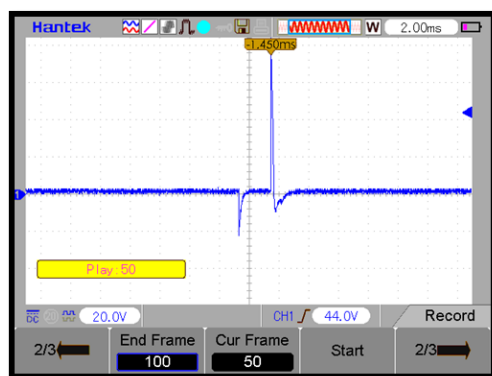


Fig.8. Oscillogram of injector control signal at the engine idle speed

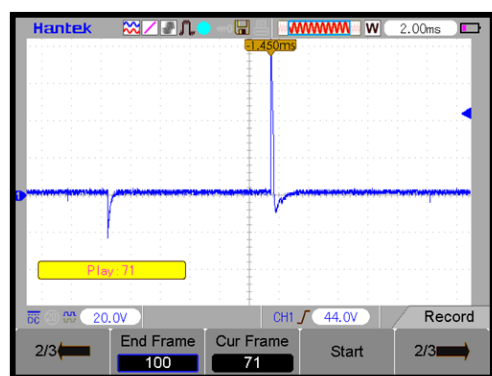


Fig.9. Oscillogram of injector control signal at the engine acceleration

According to the oscillograms the fuel injection time t_{inj} is as follows:

-start: $t_{inj} = 14$ ms;

-idle: $t_{inj} = 3$ ms;

-acceleration: $t_{inj} = 12$ ms.

It should be noted that the recorded oscillograms are at zero engine load. When increasing the load on the engine, the value of the t_{inj} also increases.

It can be seen that t_{min} and t_{inj} have comparable values only at engine idle. In all other cases $t_{min} << t_{inj}$, which means that the calculations performed are of sufficient reliability.

5. Conclusion

An approach for calculating the electromagnetic parameters of automotive electromagnetic gasoline injectors for manifold injection (multi-point injection) is presented.

The criteria minimum trigger time t_{min} and minimum electromagnetic force P_{min} are proposed to assess the electromagnetic parameters of automotive electromagnetic gasoline injectors for manifold injection.

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FEATURES OF HYBRID ELECTRIC VEHICLE (HEV) TRANSMISSION

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Abstract: The transmissions of HEVs or so-called hybrid transmissions (HT) are essentially power split transmissions, which almost always require planetary gears to split or sum up power. An essential prerequisite for reading and studying hybrid transmissions is the knowledge of planetary gear function and calculation. For example, the Toyota hybrid system can only be clarified using the principles of the planetary mechanism. In addition to Toyota's decision, there are two modes of transmission (BMW, Daimler and GM) and many patent applications with similar ideas.

Technically speaking, these solutions are power split transmissions that turn into a hybrid system by adding an electric motor (EM), a generator (G) and an electric storage battery (SB). These transmissions perform the functions required for vehicles with an internal combustion engine, such as the HEV.

These functions are launching, torque and speed conversion, reverse gear, and rapid gear-shifts in ascending or descending order. In addition, the requirements for HT are realized with the help of electronic control. For parallel HEV, a conventional gearbox plus EM is used. The automatic transmissions used in the mixed HEVs are designed with planetary gearboxes and are also known as automatic HTs. This article discusses the features of planetary gearboxes used in HEVs transmissions.

Keywords: HEV, TRANSMISSION, FEATURES

Introduction

Almost all today's automatic transmissions use planetary gears for torque conversion. Depending on the switching device of individual planetary gears, both multi-disc brakes and multi-disc clutches [1,2,3,4] are used.

There is another application for planetary gearboxes, suitable for distribution of the power flow in HEV. Here, the possibility of torque distribution and, in the case of HEV speed control, is used in two branches - the internal combustion engine (ICE) and the electric motor/generator (MG).

This allows to improve the efficiency of transmission components, which may be mechanical, hydrostatic, hydrodynamic or electrical. Such systems are increasingly being used today. Thus, this application can be found in hybrid drives and stepless hydrostatic gearboxes. Planetary gearboxes are flexible and suitable, especially for power transmission gearboxes, because in this case they are a central component.

Features of an 8-speed gearbox for a hybrid electric vehicle

In order to better understand the characteristics of the HEV gearboxes, the example of the 8-speed automatic transmission ZF (Zahnradfabrik Friedrichshafen) [1,5] was used. This product can be fitted as a "classic automatic transmission" (8 hp) as well as a hybrid solution (8P). Several combinations can be selected. Figure 1 shows an embodiment as a hybrid transmission.

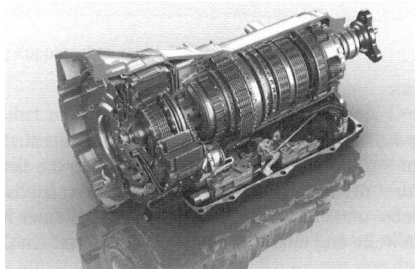


Fig. 1. Hybrid transmission box 8p70h from ZF [1]

With four planar rows and five friction elements, eight forward gears and one rear gear are formed. This new structure is developed

using computer programs that create and compare all possible connectivity options. Appropriate criteria, such as speed and torque adjustments, determine variants for gear shifting.

A very large number of bindings must be examined, so only with powerful computer systems. Top software products such as CATIA V5, which is a leading product for almost all industrial enterprises [6], and the high-end PTC Creo software development software [9] apply. This includes design offices performing specialized activities such as tolerance analysis, specialized strength calculations and so on. [7]. Strong analysis and assessment of the load and the dangerous sections and sections is a final stage and a verification of the design results [8].

This gear box is a base for a series of power ranging from 140-300 kW and inputs from 300-1000 Nm with four planned dimensions.

The design of automatic transmissions for HEV depends on the drive structure. In these cases, the hydrodynamic torque transformer is no longer needed and in this transmission the multi-disc oil trough clutch is offered as a source element in a neutral way. It is also possible to install an MG to start the ICE and also transmit power at parallel HEV between the ICE and the mechanical transmission. The all-wheel drive variant is part of the scope of the program in these transmissions, as the share of all-wheel drive vehicles is growing among the more powerful HEVs.

Figure 2 shows a sectional view of this gearbox with all indications. The brakes A and B, the clutches C, D and E and the planet rows 1 to 4 are respectively indicated. Instead of the hydrodynamic component, it is possible to integrate a multi-disc clutch into an oil tank or, in a hybrid construction, to place the MG in the existing installation space. This has the advantage that the manufacturer has virtually no installation problems, as the hybrid version is almost identical to the standard transmission.

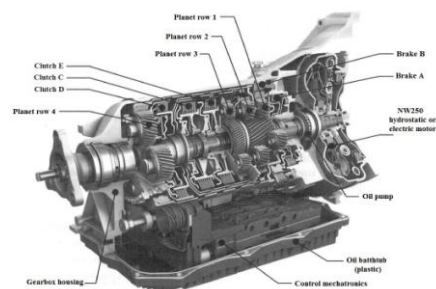


Fig.2. A section of the 8-speed automatic transmission for HEV [1]

Transmission technology requires an additional electric oil pump. It is located parallel to the oil pump with mechanical drive. The reason is that MG generates HEV zero torque (idle) and the transmission has to drive the corresponding shifting gears. This is advantageous for increasing the moment when starting in MG mode.

The scheme of this automatic gearbox is shown in Figure 3.

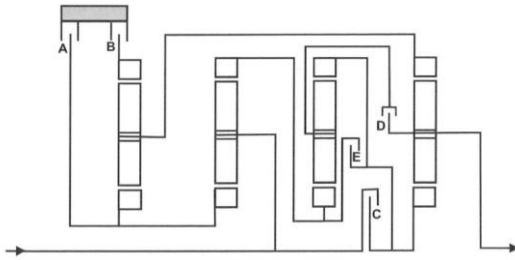


Fig.3. ZF schematic 8-speed automatic transmission for HEV [1]

Using the scheme according to FIG. 3, a Wolf diagram is produced (Fig. 4) and the number of teeth is entered.

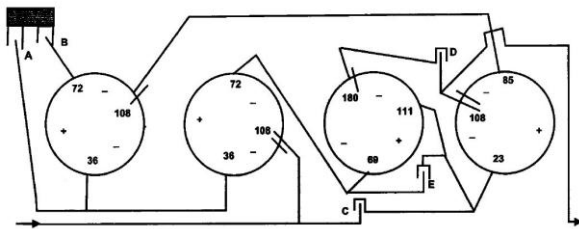
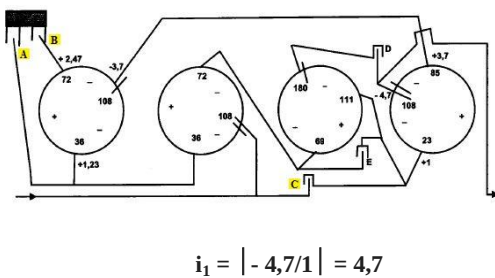


Fig.4. Wolf ZF scheme for 8-speed automatic transmission for HEV [1]

The first gear (Fig. 5) is almost classic with the brakes **A** and **B** and clutch **C**. The sun wheel on the fourth row is connected to the clutch **C**. The advantage of this switching is about 2.5 times less torque input the transmission for the brake **B** at a total gear ratio of 4.7.

1st gear: brakes A and B clutch C are engaged

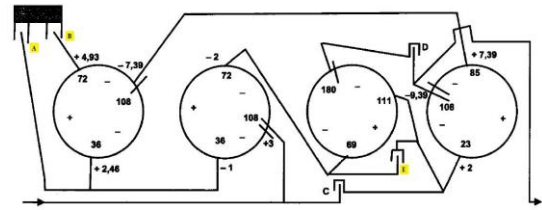


$$i_1 = |-4,7/1| = 4,7$$

Fig.5. ZF 8-speed automatic transmission for HEV - first gear [1]

The second gear is also formed by the brakes **A** and **B**, now the clutch **E** is engaged and the ring wheel of the second row is connected to the sun wheel the fourth row (Fig. 6).

2nd gear brakes A and B and clutch E are engaged

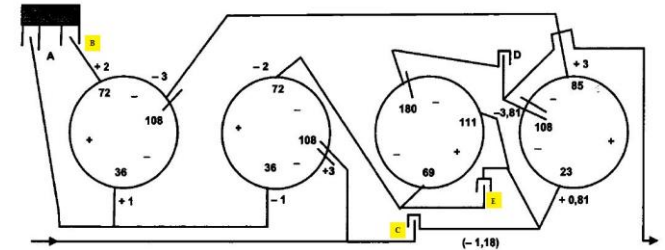


$$i_2 = |-9,39/3| = 3,13$$

Fig. 6. ZF 8-speed automatic transmission for HEV - second gear [1]

In the third gear, brake **A** is off and clutch **C** is on. This leads to a connecting shaft between the two sun wheels on the 1st and 2nd planet rows. To offset the torque (-2) of the ring wheel of the second row, the difference must be supplemented by the torque of the engine to the sun wheel of the last row (+0.81) (Figure 7).

3rd gear brake B and clutches C and E are engaged

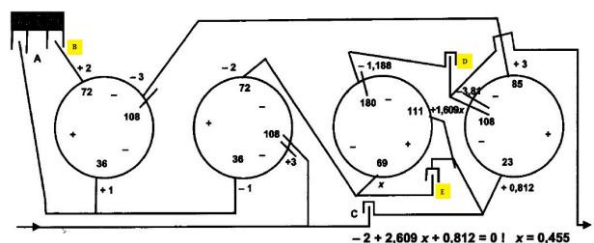


$$i_3 = |-3,81/(3-1,18)| = 2,104$$

Fig.7. ZF 8-speed automatic transmission for HEV - third gear [1]

Determining the fourth gear with brake **B** and **D** and **E** is a bit more difficult. Helping to know is the ratio of torque of the sun and ring wheel of third row. This can be done by means of the clutch shaft between the sun wheel of the first row and the ring wheel of the second row. The fourth row determines the factor x , and hence the moment of the arm on the third planet row (Figure 8).

The 4th gear brake B and the D and E clutches are engaged



$$i_4 = |-4,998/3| = 1,667$$

Fig.8. ZF 8-speed automatic transmission for HEV - fourth gear [1]

The fifth gear is formed by changing the clutches **E** and **C**. The clutch **C** is switched on and the clutch **E** is off. All planet rows are involved in this gear. In addition to the second planet row torque, the engine must also maintain the torque applied to the clutch shaft between the third row ring wheel and the fourth row sun wheel via clutch **C** (Fig. 9).

5th gear brake B and clutches C and D are engaged

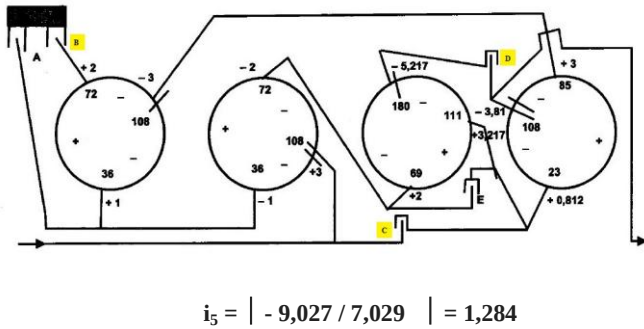


Fig. 9. ZF 8-speed automatic transmission for HEV - fifth gear [1]

The sixth gear is the result of clutch E engaged and brake B disengaged. Now all the clutches are engaged and a direct gear with a ratio of $i_6 = 1$ is obtained. In this case, the third planet row operates, with the clutches C and D, transmitting the full torque of the engine. Clutch E must absorb the proportional torque from the sun wheel (on a third planet row). This is 38.3% of the input torque (Figure 10).

The 6th gear clutches C, D and E are engaged

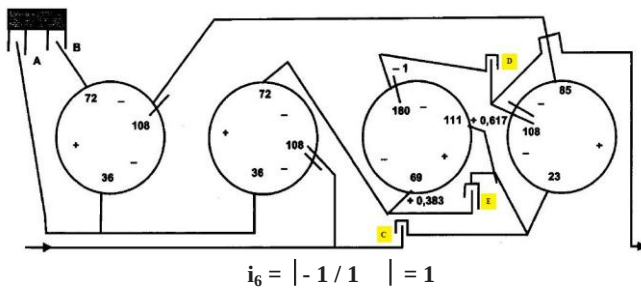


Fig.10. ZF 8-speed automatic transmission for HEV - sixth gear [1]

By disengaging the clutch E and engaging the brake A, the seventh gear is obtained. Only second and third planet rows are used to make this gear. Only the division of incoming torque through the fixed connection (guided on 2nd and 3rd planar row) and the clutch C (Fig. 11) should be taken into account here.

7th gear brake A and clutches C and D are engaged

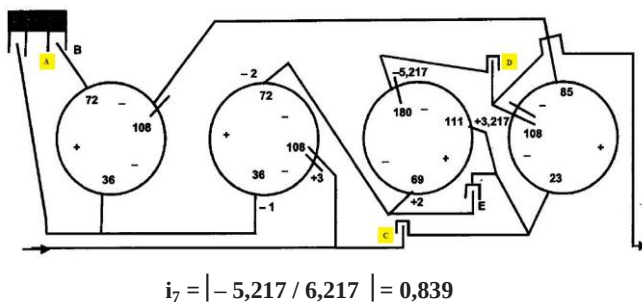


Fig.11. ZF 8-speed automatic transmission for HEV - seventh gear [1]

The eighth and thus "fastest" driving speed is the result of the switching of the clutches C and E, where C is disengaged and E is engaged. In place of clutch C, clutch D is engaged. Like the fourth gear, the clutch shaft between the second row sun wheel and the third row sun wheel is critical. Since the relation between the sun

and ring wheels of the 3rd planet row is, the factor x and the output torque can be determined (Figure 12).

8th gear brake A and clutches D and E are on

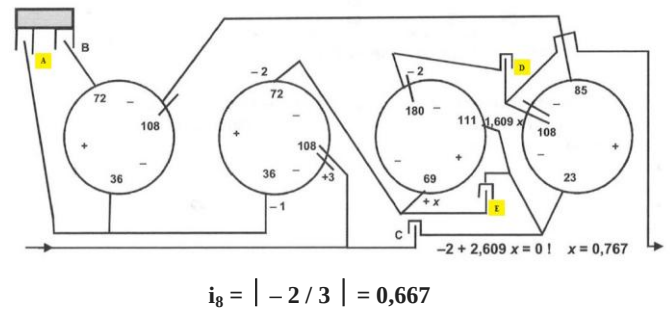


Fig.12. ZF 8-speed automatic transmission for HEV - eighth gear [1]

The required reverse gear - with the reversal of the direction of rotation in the same direction of torque transmission - is formed by both the brakes A and B and the clutch D. Starting from the drive on the second planet row, respectively, the third and fourth planet row perform the reverse gear (Figure 13).

R gear brakes A and B and clutch D engaged

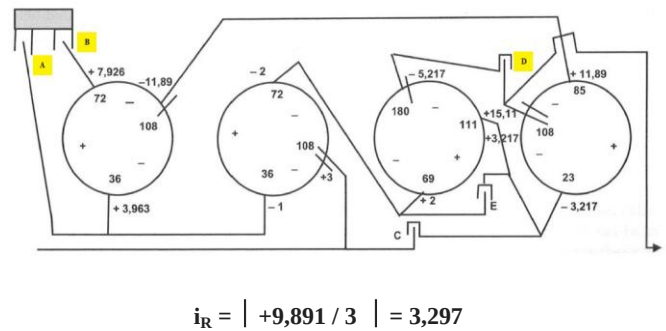


Fig.13. ZF 8-speed automatic transmission for HEV - reverse gear [1]

gear	brakes		clutch			gear ratio	Increase torque
	A	B	C	D	E		
1	●	●	●		●	4,7	
2	●	●	●		●	3,13	1,50
3		●	●		●	2,104	1,49
4		●	●	●	●	1,667	1,26
5		●	●	●		1,284	1,30
6			●	●	●	1	1,28
7	●		●	●	●	0,839	1,19
8	●			●	●	0,667	1,26
R	●	●		●		3,297	

Fig.14. ZF chart of the 8-speed automatic transmission for HEV [1]

The diagram in Fig. 14 shows the variants of ZF 8-speed automatic transmission for HEV.

As shown in Figure 14, there are eight harmonic stepped ratios that make sense for the modern vehicle transmission. The condition that a switching element is always switched off and another is switched on in ascending order with one gear is clearly visible in this diagram. In principle, three of the five switching elements are always included, and therefore only two elements are always excluded.

Conclusion

The mention above certainly has advantages in reducing unavoidable idle losses. Together with this very "clever" clutch structure and extended oil spreading, a 6% saving potential is achieved compared to the 6-speed automatic transmission, this 8-speed automatic transmission is no more severe than the 6-speed automatic transmission. With this product, the number of planetary rows and XPS planetary gearbox sizes will continue to grow. In addition to this ZF product, an eight-speed Aisin gearbox has been developed and Daimler AG already has a 9-speed automatic transmission in its program. The management of these planetary gearboxes is inextricably linked to actuators, which are essentially electromagnetic devices [10] activated by the HEV electronic control unit.

ACKNOWLEDGEMENT

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A RESEARCH INTO THE EFFECT OF ATMOSPHERIC TURBULENCE ON THE MOTION OF A QUADROPTER WITH PID CONTROL

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Abstract: This report looks at Dryden's atmospheric turbulence model. Applying the turbulent model to the motion of a quadrocopter with PID control. Analysis of the impact of atmospheric disturbances on a quadrocopter flight.

Keywords: DRYDEN, ATMOSPHERIC TURBULENCE, QUADROPTER, PID CONTROL

1. Introduction

All types of aircraft are influenced by atmospheric turbulence and air currents. Depending on the size, type and height of the flight, atmospheric disturbances influence them differently. [5, 6]. One and the same disturbance, acting on a unmanned airplane flying high altitude [2], for example UAV Predator, and on the quadrocopter[4] flying several meters above the ground, will have little or no impact on flight parameters in the first case, and from there on the proper performance of the task, while in the case of the quadrocopter it can lead to a collision with the ground or a nearby obstacle (a building, a tree, etc.)[1]. This requires modeling and research of the quadrocopter movement, using different control methods in the presence of atmospheric disturbances.

2. Model of atmospheric turbulence.

In modeling the atmosphere, the most widely distributed model is the International Standard Atmosphere [8].

The reason for the occurrence of air currents is the uneven distribution of air pressure in the atmosphere. Depending on the season, the place above the ground, the relief of the area and the presence of vapors in the atmosphere, the air is heated differently by the sun. What is more, significant differences in temperature between the different layers in the horizontal and vertical directions appear resulting in a change in the density and pressure. Therefore, the solar-transmitted thermal energy is transformed into movement of air particles. They move at different speeds in different directions. If the particle speed exceeds a certain limit, the motion becomes turbulent. Such movement is of a random nature and is accompanied by significant vortices forming [10, 13].

All air currents can be divided into two types: vertical and horizontal.

Vertical currents include ascending and descending streams, cloudy streams and vortices. The influence of these currents on the flight depends on the size of the vertical component of the air velocity, the spatial area occupied by the current, the velocity of the flight, etc.

Horizontal currents include constant by size and direction winds, wind strata, gusts, waves and whirlwinds.

Each air flow is accompanied by vortex generating. In this case, the higher the flow velocity, the higher the speed of the vortex. The formation of vortices is the result of the turbulent air movement. Turbulence is caused by friction of the air with the surface of the ground, heat movement, friction between the air layers, etc.

The whirlwinds accompanying the turbulent motion may have a vertical or horizontal axis of rotation, and more commonly encountered are the ones with a horizontal axis of rotation.

In an urban environment quadrocopter flight, the presence of an air stream or a gust of wind may cause a strong turbulence to occur in unexpected locations. The reason for this is the interaction of air masses with different buildings [11].

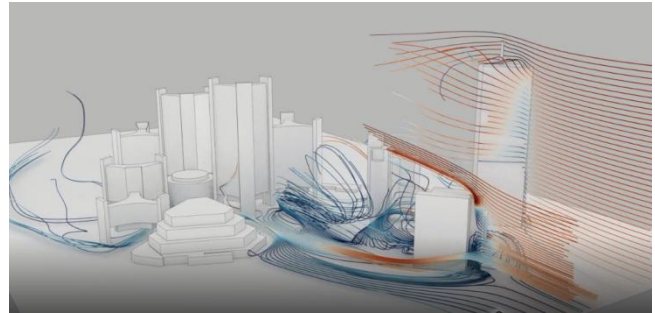


Fig. 1 Turbulence in urban conditions [12].

In the modeling of turbulence, the Dryden and Karman models are most commonly used [9].

There, the variable component of wind speed is described by statistical methods. All of the models use, to a certain degree, assumptions about: homogeneity, isotropy and stationarity. Under these assumptions, the statistical characteristics depend only on the distance between the points and the averaging interval.

The wind distribution in space is considered to be frozen and, depending on the time, it is assumed that the airplane pierces this distribution (Taylor hypothesis). For isotropic turbulence estimation, two components of the random wind speed are used: component of the tangent to the trajectory V_t and the normal component V_n .

The statistical processing of experimental results is reduced to approximation with empirical formulas, where spectral densities are fractionally rational functions of the frequency. [3, 9]. Thus, wind influences are represented as white noise that goes through linear forming filters with a classical structure. The spectral density functions are [9] :

$$\begin{aligned} (1) \quad S_u(\Omega) &= \sigma_u^2 \frac{2L_u}{\pi} \frac{1}{1+(L_u\Omega)^2}; \\ (2) \quad S_v(\Omega) &= \sigma_v^2 \frac{2L_v}{\pi} \frac{1+12(L_v\Omega)^2}{(1+4(L_v\Omega)^2)^2}; \\ (3) \quad S_w(\Omega) &= \sigma_w^2 \frac{2L_w}{\pi} \frac{1+12(L_w\Omega)^2}{(1+4(L_w\Omega)^2)^2} \end{aligned}$$

where : σ - is the dispersion of the turbulent movement;

L - scale of turbulence;

Ω - spatial frequency;

S - a distance between two points of the turbulence field.

3. Modeling of quadrocopter flight with PID control in turbulent environment.

A mathematical model of a real class 500 quadrocopter was made consisting of the following equations.

The equations for the translational motion are obtained as a consequence of the theorem of varying the amount of motion.

$$(4) \quad m \frac{d\vec{V}}{dt} = \sum \vec{F}$$

After substitution, the full differential equations for the movement of the center of mass of the quadcopter are obtained:

$$(5) \quad \dot{V}_x = \frac{dV_x}{dt} = \frac{F_x}{m} - \omega_y V_z + \omega_z V_y;$$

$$(6) \quad \dot{V}_y = \frac{dV_y}{dt} = \frac{F_y}{m} - \omega_z V_x + \omega_x V_z;$$

$$(7) \quad \dot{V}_z = \frac{dV_z}{dt} = \frac{F_z}{m} - \omega_x V_y + \omega_y V_x.$$

The external forces acting on the axis of the coupled coordinate system of the quadcopter are:

$$(8) \quad F = \begin{bmatrix} F_x \\ F_y \\ F_z \end{bmatrix} = \begin{bmatrix} -G \sin(\vartheta) \\ (\omega_1^2 + \omega_2^2 + \omega_3^2 + \omega_4^2)k - G \cos(\gamma) \cos(\vartheta) \\ G \sin(\gamma) \cos(\vartheta) \end{bmatrix},$$

where $f_i = k\omega_i^2$ is the thrust generated by the i -th engine;

$G \cos(\gamma) \cos(\vartheta)$ is the force of gravity directed at the local vertical.

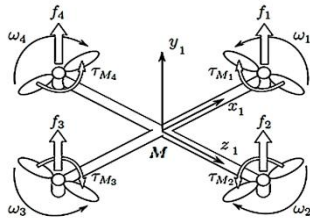


Fig.2 The forces and the moments in quadcopter flight.

The description of the movement around the center of mass is carried out by integrating the derivative of the kinetic moment:

$$(9) \quad \frac{d\vec{K}}{dt} = \sum \vec{M}$$

Complete equations for rotary motion around the center of the mass are:

$$(10) \quad \dot{\omega}_x = \frac{1}{I_x} [M_x - (I_z - I_y) \omega_y \omega_z];$$

$$(11) \quad \dot{\omega}_y = \frac{1}{I_y} [M_y - (I_x - I_z) \omega_x \omega_z];$$

$$(12) \quad \dot{\omega}_z = \frac{1}{I_z} [M_z - (I_y - I_x) \omega_x \omega_y].$$

The quadcopter has a symmetrical structure with four propellers. Therefore, the cross inertia moments are very small and can be ignored.

The angular velocity of the rotor i , designated ω_i , creates a force f_i in the direction of the axis of the rotor. The angular velocity and the acceleration of the rotor also create a reactive moment τ_{Mi} around the axis of the rotor [7].

$$(13) \quad \tau_{Mi} = b\omega_i^2 + I_M \dot{\omega}_i,$$

where: b is a constant, proportional to the reactive moment,

I_M is the inertia moment of the rotor.

Usually, the effect of the change in angular velocity is considered to be small, and is therefore omitted.

External moments acting on the axis of the body-fixed frame are:

$$(14) \quad \vec{M} = \begin{bmatrix} M_x \\ M_y \\ M_z \end{bmatrix} = \begin{bmatrix} hk(-\omega_1^2 - \omega_2^2 + \omega_3^2 + \omega_4^2) \\ \tau_{M1} - \tau_{M2} + \tau_{M3} - \tau_{M4} \\ hk(\omega_1^2 - \omega_2^2 - \omega_3^2 + \omega_4^2) \end{bmatrix},$$

where - h is the distance between the rotor and the corresponding axis of the body-fixed frame.

The angular position of the quadcopter relative to the ground coordinate system $Ox_1y_1z_1$ is set by three angles: ψ - Yaw, γ - Pitch, ϑ - Roll. The relationship between these angles and the angular velocities around the axes of the body-fixed frame are given by the following differential equations:

$$(15) \quad \dot{\psi} = \frac{\omega_y \cos \gamma + \omega_z \sin \gamma}{\cos \vartheta},$$

$$(16) \quad \dot{\gamma} = \omega_x + \tan \vartheta (\omega_y \cos \gamma + \omega_z \sin \gamma),$$

$$(17) \quad \dot{\vartheta} = \omega_y \sin \gamma + \omega_z \cos \gamma.$$

The spatial displacement of the quadcopter is described by means of the guiding matrix of directing cosines and the linear velocities in the body-fixed frame.

$$(18) \quad \begin{pmatrix} \dot{X} \\ \dot{Y} \\ \dot{Z} \end{pmatrix} = C_{(\psi, \vartheta, \gamma)} \begin{pmatrix} V_x \\ V_y \\ V_z \end{pmatrix}.$$

The system of equations (5 ÷ 8, 10 ÷ 18) is realized in the environment of Simulink. Four PID regulators are added to control flight height and angles ψ , ϑ and γ . Atmospheric disturbances are presented with a Dryden model [14] and are added to the closed system (fig. 3).

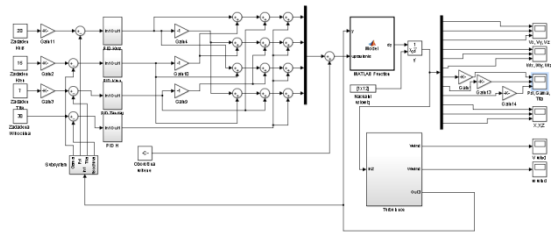


Fig.3 Quadcopter flight model with added atmospheric disturbance.

4. Results

Fig.4 shows the working of predetermined angles ψ , ϑ and γ from the quadcopter without added interference.

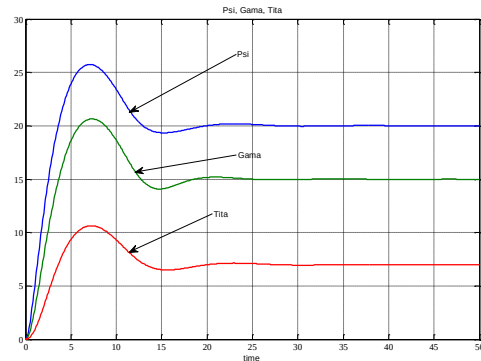


Fig.4 Angles of Yaw ψ , Pitch γ and Roll ϑ without added interference.

Figures 5 and 6 show the turbulent disturbances acting on the axes of the body-fixed frame. They are generated under the following conditions:

- Wind speed at the low-altitude – 8 (m/s);
- Probability of exceedance of high-altitude intensity: 10^{-2} ;
- Scale length at medium/high altitudes: 533.4(m).

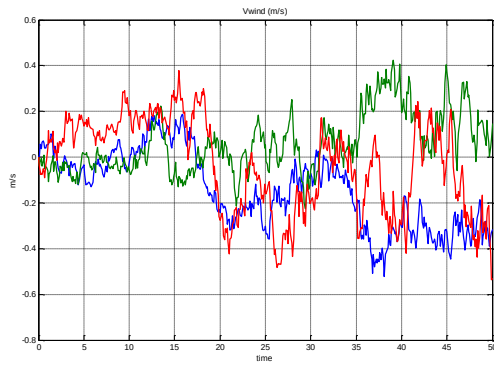


Fig.5 Disturbances in the form of linear velocities on the axes of the body-fixed frame, in meter per second.

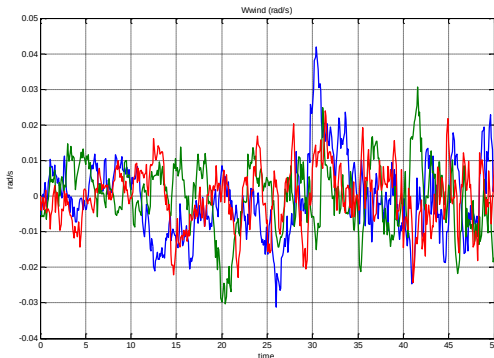


Fig.6 Whirlwind disturbance on the axis of the body-fixed frame, in radians per second.

In fig. 7 is shown the influence of the disturbances on a quadcopter flight without change in the setting of PID controller shown in fig.5 and fig.6.

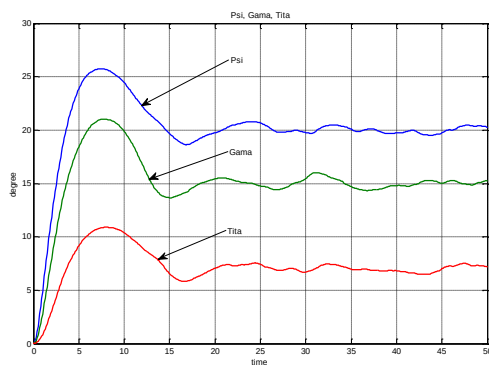


Fig.7 Angles of Yaw ψ , Pitch γ and Roll θ with added interference.

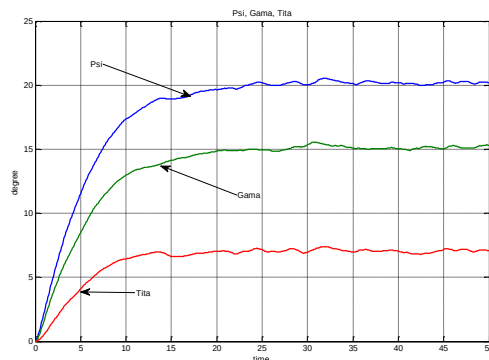


Fig.8 Angles of Yaw ψ , Pitch γ and Roll θ with added interference and increased robustness of regulators.

Changing the setting of PID controllers by increasing the robustness of the system reduces the impact of atmospheric disturbances but reduces the speed of the system. Figure 8 shows the change of the angles of Yaw ψ , Pitch γ and Roll θ under the same initial conditions, with added disturbances and with the new settings of the PID regulators.

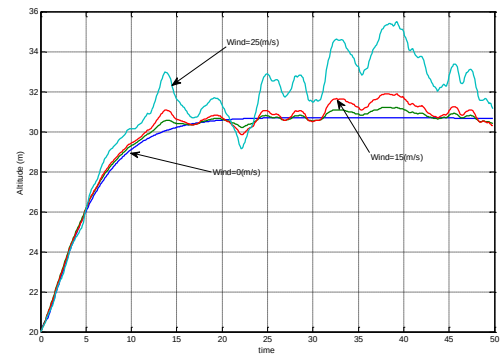


Fig.9 Flight height variation at different wind intensities and increased system robustness.

Figure 9 shows the variation in flight height at different wind intensities and increased system robustness.

From Figures 7, 8 and 9 the following conclusions can be made:

- Angles Yaw ψ , Pitch γ and Roll θ , defining the spatial position and behavior of the quadcopter, are influenced by the intensity of the wind, but with increasing system robustness, this influence weakens;

- The change in wind intensity has a greater effect on flight height than its angular position, and increased robustness can not compensate for atmospheric turbulence.

5. Conclusions

1. A mathematical model of a real quadcopter is created;
2. The motion of a quadcopter is modeled in the presence of atmospheric disturbances;
3. From the results obtained, it is possible to determine the upper limit of the atmospheric disturbances in which a quadcopter can be used;
4. The quadcopter whose model has been studied can be used in open spaces at winds up to 25 (m / s) and in urban environments at winds up to 10 (m / s).

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FINDING THE OPTIMAL COMPENSATOR CONTROL MATRIX IN THE LONGITUDINAL CHANEL FOR DEVELOPED MUAV

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Abstract: The presented report examines the isolated longitudinal movement of a mini unmanned air vehicle type flying wing. The overall dimensions and the mass characteristics are taken from the developed MUAV. These features are introduced into the software environment of the virtual aerodynamic tunnel. The resulting mathematical model is statically balanced in the isolated longitudinal movement and the openloop system has been stability examined. The received state matrix is introduced into the state space model of the isolation longitudinal movement and the system is tested for stability and controllability. A matrix of the compensator is synthesized, and its optimal coefficients are found by two methods.

Keywords: MUAVs, VIRTUAL WIND TUNEL, OPTIMAL COMPENSATOR CONTROL MATRIX

ОПРЕДЕЛЯНЕ НА ОПТИМАЛНАТА КОМПЕНСАТОРНА МАТРИЦА НА УПРАВЛЕНИЕТО В НАДЛЪЖНИЯ КАНАЛ ЗА РАЗРАБОТЕН МБЛА

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1. Introduction

The safety is an important factor in the sustainable development of the society [9]. The modern world has become more and more insecure. This uncertainty leads to crises, whose analysis, risk factors and characteristics become more and more diverse [4]. It is particularly convenient to use aviation in operations in response to large-scale disasters [3].

In this dynamic security environment, unmanned aerial vehicles (UAVs) are increasingly finding their place and application. The manufacturers of UAVs strive to make them more efficient and reliable. For this purpose, a number of methods for forecasting the technical condition of the aviation equipment installed on board are used [5], [6].

In addition to the aviation equipment, UAVs efficiency and reliability depend on the design methods of their construction [13], the choice of a geometric schem with the suitable aerodynamic quality [11] and the studies that are made in this direction with real [14] and virtual [16] aerodynamic tunnels. The use of software products to study the aerodynamic characteristics of the airfoils and wings is growing. For this purpose an appropriate free product is XFLR5 [17].

Computer systems and software products shorten the time when developing the mathematical models of the UAVs movement [7], [18] and through them the synthesis of suitable autopilots and automatic control systems are made. Especially important here are real experiments as well as technical means and algorithms for flight information processing [2]. The data from these experiments are obtained from the on-board equipment and the ground control station [1] using the sensors included therein [12].

The main purpose of this study is with the free software product XFLR5 in its virtual aerodynamic tunnel environment to be made a research of the developed mini UAV (MUAV) to produce the state space matrix for isolated longitudinal motion. After that, a mathematical model of the motion in the longitudinal channel to be developed. Then, an appropriate control by optimizing the compensation control matrix to be synthesized.

2. Testing MUAV in a XFLR5 wind tunnel

A flying wing aircraft type was developed, from which the shape of the airfoils and the overall dimensions of the planer were taken. The airfoils from which the wing of the MUAV is made are drawn in the XFLR5 software airfoil section environment. After that, the airfoil aerodynamic characteristics have been investigated. Using the downloaded dimensions of the MUAV and the previously drawn aviation airfoils the whole sailplane was drawn in the aircraft section environment of the same software product.

On the drawing MUAV, the locations of the main parts, such as the battery, the autopilot, the steering gear, etc., have been defined, and their mass characteristics are set. Based on mass features, the XFLR5 software calculates the inertia moments and the center of gravity of the MUAV.

For the purpose of the study, only the longitudinal channel of the isolated longitudinal movement of the MUAV is considered. Range of speeds and angles of attack were set and the aerodynamic characteristics of the MUAV were taken. The experimental setting of the study is shown in Figure 1.

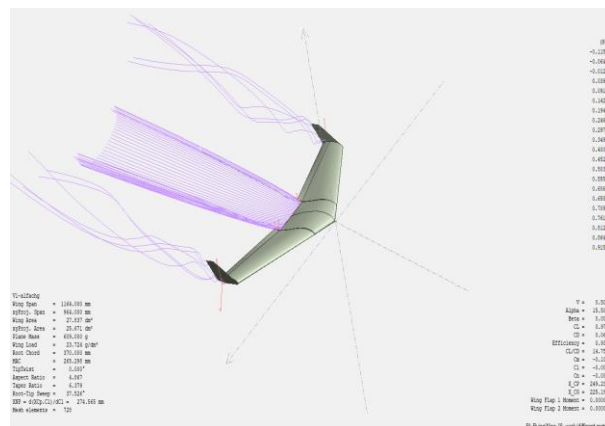


Fig. 1 Testing MUAV in a XFLR5 wind tunnel environment.

A static balancing of the MUAV has been performed by deviating the end portions of the airfoils where are the steering wheels of the real aircraft. After the static balancing, the movement

of the MUAV in the isolated longitudinal direction of the flight was investigated at the specified frequency and the amplitude of the disturbances.

In the event of atmospheric disturbances in the vertical plane, a longitudinally-oriented horizontal flight of the MUAV is performed by two types of movements: short periodic and long periodic [10]. The short period movement in the the XFLR5 environment is shown in Figure 2. It is high frequency a vertical movement at the same time with the angular velocity of the pitch. This movement is well damped, but it is difficult for the operator of MUAVs because it is invisible.

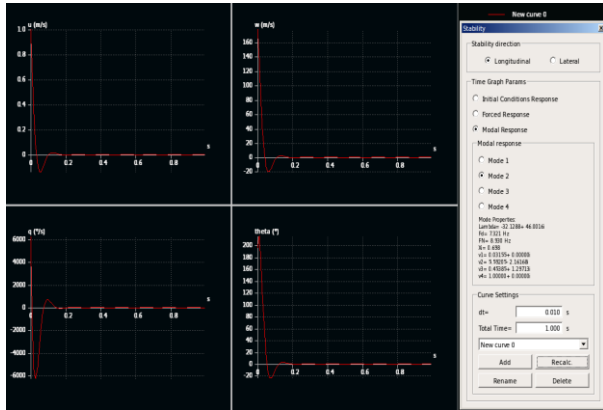


Fig. 2 Short time period movement in longitudinal channel simulated in XFLR5 environment.

The long-period movement is described by a figure called the fugoid and is shown in Figure 3. In the execution of this movement, the lift force is changed by converting the kinetic energy into potential and vice versa when diving and climbing the MUAV.

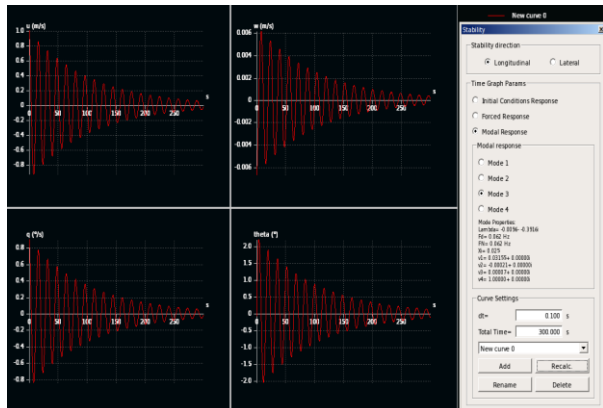


Fig. 3 Long time period movement in longitudinal channel simulated in XFLR5 environment.

The two movements in the isolated longitudinal channel (long and short periodical) are fluctuating in nature. The capabilities of the XFLR5 software product include depicting the location of roots of the characteristic equation for short-period and long-period motion.

The rootlocus position in the complex plane is shown in Figure 4. In this figure, the roots of the short-period movement are far at the left, while the long-periodic ones are close to the imaginary axis.

The characteristic equation is obtained from the state space matrix of the longitudinal isolated movement [15], composed by expression (1):

$$A = \begin{bmatrix} X_u & X_w & 0 & -g \\ Z_u & Z_w & u_0 & 0 \\ M_u + M_w Z_u & M_w + M_w Z_w & M_q + M_w u_0 & 0 \\ 0 & 0 & 1 & 0 \end{bmatrix} \quad (1)$$

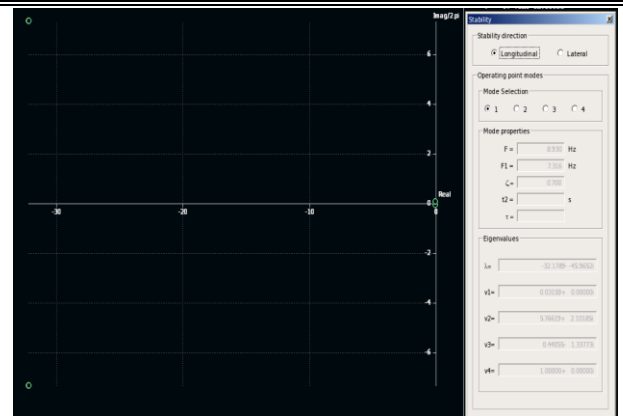


Fig. 4 Openloop root locus of characteristic equation shown in XFLR5.

The numeric expression values (1) for the longitudinal state matrix the found in the XFLR5 software product are shown in (2):

$$A = \begin{bmatrix} -0.0222984 & 0.00822439 & 0 & -9.81 \\ -0.619111 & -30.6397 & 26.6356 & 0 \\ 6.70861e-6 & -79.5329 & -33.6149 & 0 \\ 0 & 0 & 1 & 0 \end{bmatrix} \quad (2)$$

When the MUAV is subjected to disturbance, it has a physically tends to respond to different flight modes. From a mathematical point of view, these flight modes are called their own (natural) modes and are described by:

1. eigenvalues – describing the flight mode frequency and its damping;
2. eigenvectors – setting the shape of the figure in the described movement reaction.

The numerical values of the eigenvalues and the eigenvectors of this particular isolated longitudinal motion found by XFLR5 are shown in Table 1.

Table 1: Eigenvalues and eigenvectors of state matrix.

Eigenvalues (собственные числа):			
-32.13+ (-46i)	-32.13+ (46i)	-0.009611+ (-0.3916i)	-0.009611+ (0.3916i)
Eigenvectors (собственные векторы):			
1+ (0i)	1+ (0i)	1+ (0i)	1+ (0i)
177.2+ (68.51i)	177.2+ (-68.51i)	-0.00661+ (2.42e-5i)	-0.00661+ (-2.42e-5i)
108.4+ (-309.9i)	108.4+ (309.9i)	0.01564+ (0.000125i)	0.01564+ (-0.000125i)
3.421+ (4.747i)	3.421+ (-4.747i)	-0.001299+ (0.03992i)	-0.001299+ (-0.03992i)

3. Optimizing the longitudinal channel compensator control matrix

By the eigenvalues and the eigenvectors of the state matrix, it is established whether the MUAV is resistant to the isolated longitudinal movement. The study is drowned when all states in this movement are observable.

Checking for observability and controllability is done in the MATLAB environment. This is the first thing that needs to be done when designing the system using the space space method. For the states of the system to be fully observable and controllable, the rank of the matrices of observation and control must be equal to the number of independent rows (columns) of the state matrix. The result of the MATLAB environment is shown in (3):

$$\text{Controllability} = 4; \quad \text{Observability} = 4 \quad (3)$$

which means that the system is observable and controllable.

The single step function reaction of the open system is shown in Figure 5.

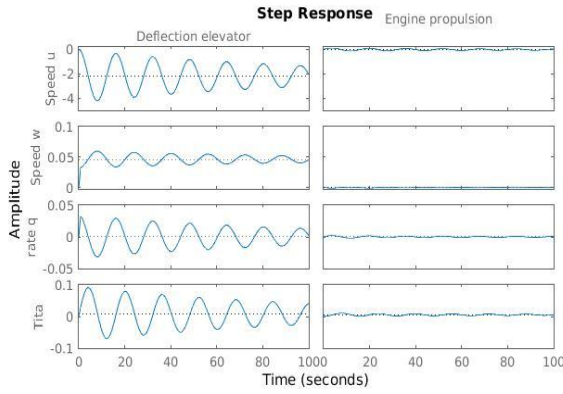


Fig. 5 Openloop step function reaction.

Figure 5 shows that the openloop system can not reach the desired state vector value. It is necessary to close the system with feedback, so that when the system is entered in the desired state, the system can reach it. Figure 6 shows a developed MATLAB-Simulink model of the closedloop system.

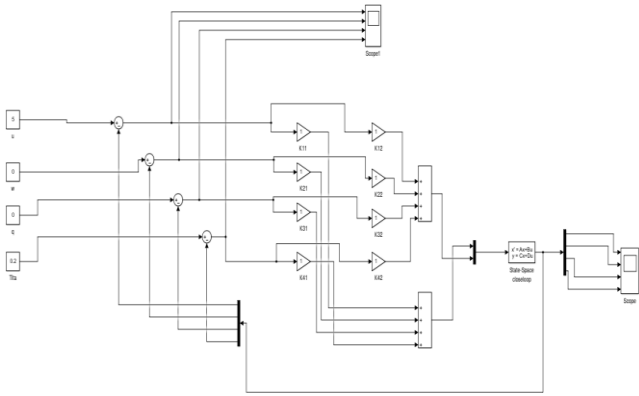


Fig. 6 Closedloop system with compensator matrix K equal to one.

Initially, the values in the compensation matrix are set to ones. The reaction of the closedloop system of the desired state is shown in Figure 7. It is necessary to find such values in the compensator matrix to control the MUAV in the isolated longitudinal movement so as to reach the desired values of the state space.

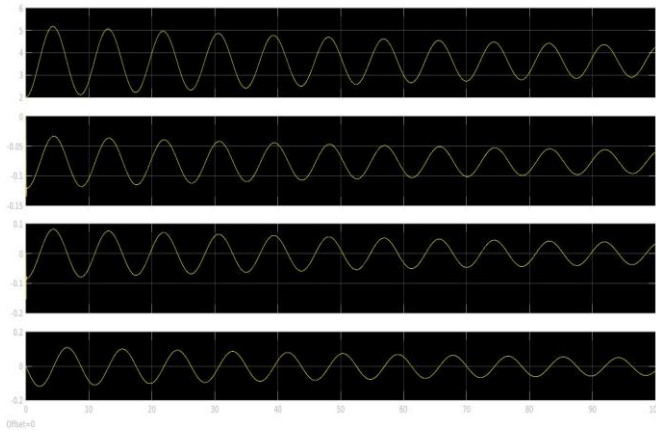


Fig. 7 The result of the closedloop system with compensator matrix K equal to one to a desired state.

In order to find the optimal values in the compensator matrix, a linear-quadratic regulator (LQR) is used to build an LQR-based compensator K .

$$J = \int_0^\infty (x^T Q x + u^T R u) dt \quad (3)$$

The idea is to minimize the function of the losses J in (3) by optimally selecting the weight matrices Q and R [8].

$$u = K(x - x_d) \quad (4)$$

The state is controlling by error (4) where x_d is the desired value. The synthesized model with LQR compensator K is shown in Figure 8, and in Figure 9 is the results of its operation.

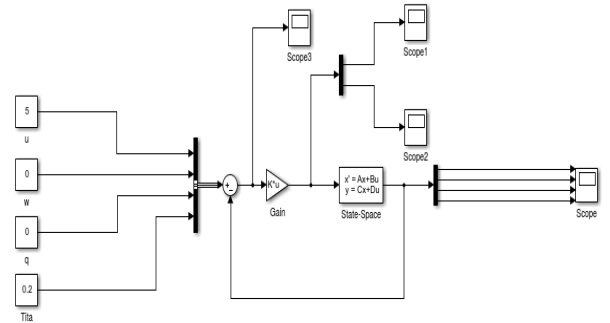


Fig. 8 Closedloop system with LQR compensator matrix K .

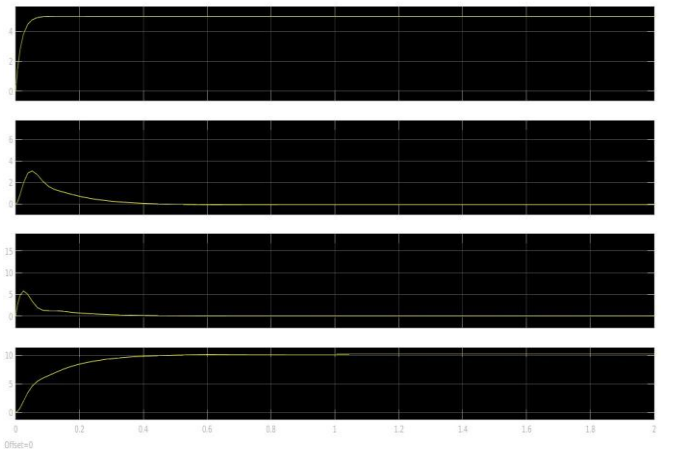


Fig. 9 The result of the closedloop system with LQR compensator K .

Another method that is convenient to use when setting the compensator coefficients is the MATLAB-Simulink-Control system Tuner option. When entering the compensator coefficients from the model in Figure 6 and determining the input and output signals in the environment of the Control system Tuner, it is necessary to select the aim of the system setting.

In this case, single step response response is selected in the channels of the horizontal velocity and trajectory angle. The pre-set reaction of the model in Figure 6 is shown in Figure 10.

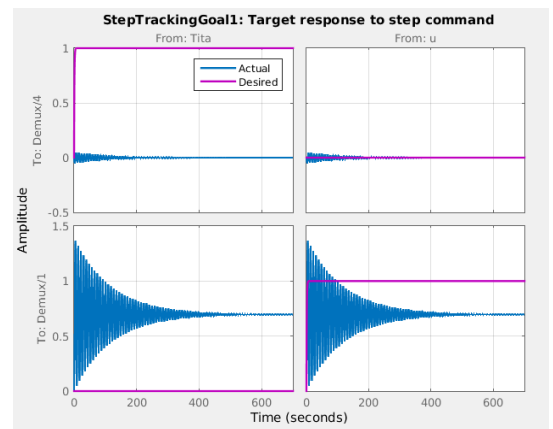


Fig. 10 Reaction system to a step function in the control channels.

After performing the automatic adjustment of the coefficients of the compensator for the system reaction response in the control channels, the results of Figure 11 are obtained.

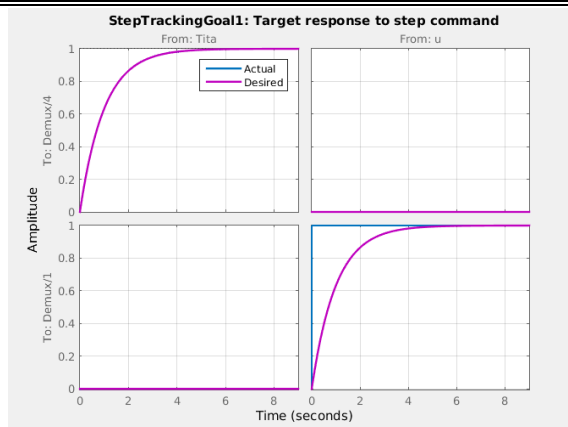


Fig. 11 The result of autotuning coefficients of the compensator.

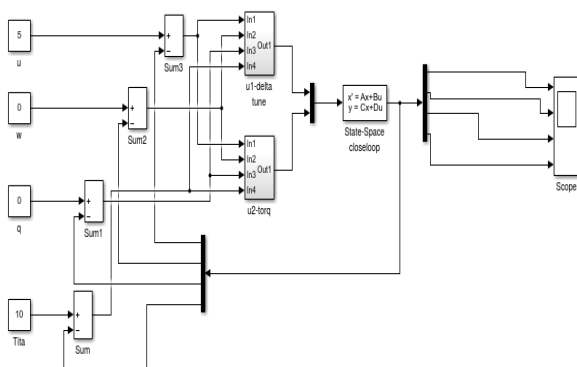


Fig. 12 The model with tuning coefficients of the compensator.

The obtained compensator coefficients are entered in the model of Figure 12 and its reaction to the desired state is shown in Figure 13.

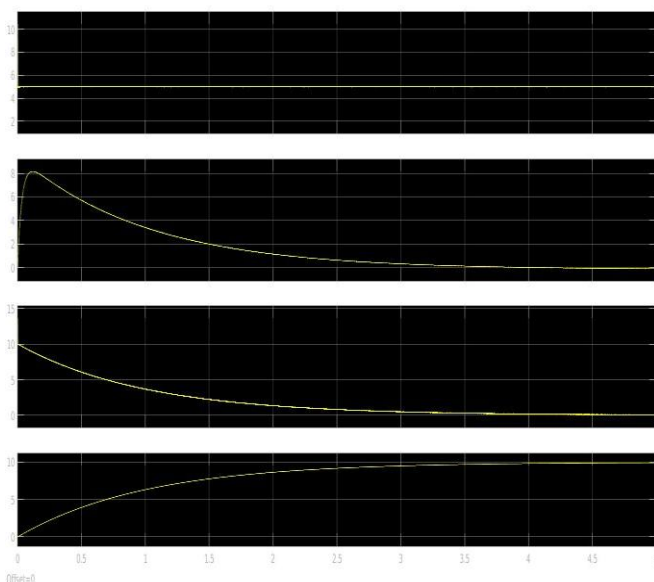


Fig. 13 The reaction to the desired state space with tuning coefficients of the compensator.

4. Conclusions and results

1. The longitudinal channel of the developed MUAV in its isolated longitudinal motion was investigated.
2. The responses of the openloop and closedloop systems of a single step signal and the desired state are compared.

3. Two methods are used to find compensator coefficients - LQR and auto-tuning.

4. The results of the two using methods are similar.

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ENERGY CONTROL PRINCIPLES IN AN AUTOMOTIVE ACTIVE SUSPENSION SYSTEM

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Abstract: In the paper, energy recuperation and management in automotive suspension systems with linear electric motors controlled using a proposed H_∞ controller to obtain a variable mechanical force for a car damper is presented. Vehicle suspensions in which forces are generated in response to feedback signals by active elements obviously offer increased design flexibility compared to the conventional suspensions using passive elements such as springs and dampers. The main advantage of the proposed solution using a linear AC motor is the possibility to generate desired forces acting between the unsprung and sprung masses of the car, providing good insulation of the car sprung mass from the road surface disturbances. In addition, under certain circumstances using linear motors as actuators enables to transform mechanical energy of the vertical car vibrations to electrical energy, accumulate it, and use it when needed. Energy flow control (management) enables to reduce or even eliminate the demands concerning the external power source.

Keywords: VEHICLE, ACTIVE SUSPENSION, LINEAR MOTOR, ENERGY FLOW, CONTROL, DISTURBANCES, ROAD

1. Introduction

The theoretical research concerning the active suspension of mechanical vibrations and improving ride comfort and handling properties of vehicles is concentrating on various suspension innovations. The main goal of the paper is to describe H_∞ controlled active suspension design with respect to the management of the energy flow distribution. In the time of growing interest in the overall minimization of energy consumption, the presented paper could be accepted as a contribution to these efforts. Especially in the application field of automotive vehicles, energy consumption optimization plays an important role in the design process.

In most active suspension systems, the biggest disadvantage consists of energy demands. Regarding linear electric motors, this drawback can be eliminated because under certain circumstances there is a possibility to recuperate energy, accumulate it and use it later when necessary. This way, it is possible to reduce or even eliminate the demands concerning the external power source. In the next chapters, we will describe the proposed strategy on how to control the energy distribution.

All suspension systems are designed to meet specific requirements. In suspension systems, usually two most important features are expected to be improved - disturbance absorbing (i.e. passenger comfort) and attenuation of the disturbance transfer to the road (i.e. car handling). The first requirement could be presented as an attenuation of the damped mass acceleration or as a peak minimization of the damped mass vertical displacement. The second one is characterized as an attenuation of the force acting on the road or in a simple car model as an attenuation of the unsprung mass acceleration. It is obvious that there is a contradiction between these two requirements. With respect to these contradictory requirements, the best results can be achieved using active suspension systems generating avariable mechanical force acting in the system.

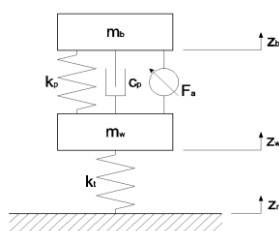


Fig. 1. One-quarter-car model

The H_∞ controller synthesis for active suspension has been done using a simple one-quarter-car model (see Fig. 1). The model

consists of a spring (stiffness k_p), passive damper (damping quotient c_p), sprung mass is taken as one-quarter of the body mass (m_b), unsprung mass representing one wheel (m_w) and a spring connecting the unsprung mass to the road and representing the tire stiffness (k_t). The active force (F_a) acting between the sprung and unsprung masses of the car is generated by a linear electric motor. For analysis and verification, we used a more complex model (see [1] for details).

1. Linear AC Motor

From the point of view of the aspects discussed above, the authentic application of a linear electrical AC motor seems to be very perspective. The beauty of linear motors is that they directly translate electrical energy into usable linear mechanical force and motion and vice versa. Compared to conventional rotational electromotors, the stator and the shaft (translator) of direct-drive linear motors are linear-shaped (see Fig.2). One can imagine such a motor taking infinite stator diameter. The direct drive AC linear motor exhibits the property of the contact-less transfer of electrical power according to the laws of magnetic induction. The electromagnetic force is applied directly without the intervention of a mechanical transmission. Low friction and no backlash resulting in high accuracy, high acceleration and velocity, high force, high reliability and long lifetime enable not only effective use of modern control systems but also represent the important attributes needed to control vibration suspension efficiently. Linear motor translator movements take place with high velocities (up to approximately 200m/min), large accelerations (up to g-multiples), and forces (up to kN). As mentioned above, the electromagnetic force can be applied directly to the payload without the intervention of a mechanical transmission, which results in high rigidity of the whole system, its higher reliability and longer lifetime. The main advantage of the proposed solution using a linear AC motor is the possibility to generate desired forces acting between the unsprung and sprung masses of the car, providing good insulation of the car sprung mass from the road surface disturbances. In addition, under certain circumstances using linear motors as actuators enables to recuperate energy i.e. to transform mechanical energy of the car vertical vibrations generated by the road disturbances to electrical energy, accumulate it, and use it when needed.

For the automotive suspension system, the application of the synchronous three-phase linear motor TBX 3810 fy Copley Controls Cooperation (technical parameters: peak force 2027N, peak current 21.8A, continuous stall force 293.2N, electrical time constant 1.26ms, continuous working voltage 320Vac, maximum phase temperature 100oC) has been designed by the research team.

It is necessary to answer one important question - if it is more advantageous to include the model of the linear electric motor in the

model for active suspension synthesis or if it should be used only for simulations.

Comparing the advantages and disadvantages of the model inclusion, it can be said that the closed-loop provides more information so that better control results can be achieved. Unfortunately, there are also some significant disadvantages to such a solution. The first one insists in the rank of the system (and consequently the rank of the controller which increases up to 5) and the second one is that the D matrix in the state space description of the motor model does not have full rank and that is why implementation functions are limited or too complicated. On the base of this comparison, the linear motor has not been included in the model for active suspension synthesis.

There is another important question whether the linear motor model could be omitted and a linear character of the desired force could be supposed. The answer is “yes”. Both the mechanical and the electrical constants are very small – just about 1ms. Moreover, it will be shown that the robustness of the H_∞ control design has been verified using numerous simulation results and experiments.

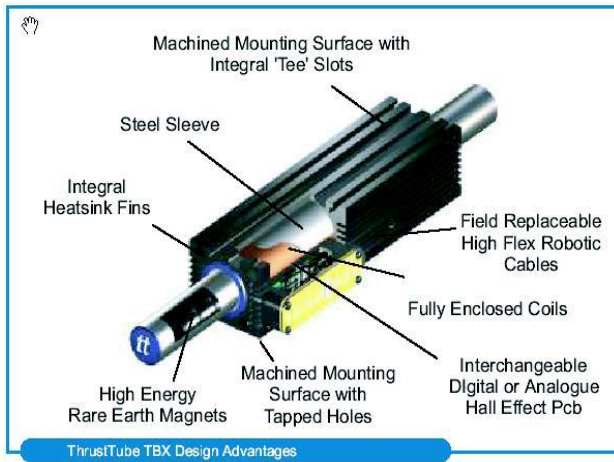


Fig. 2 Linear motor - basic design
(adapted manufacturer spreadsheet).

3. Energy balance

As mentioned above, linear electric motors are able to recuperate energy. When the generated force is of the same direction as the suspension velocity, the energy has to be supplied into the system. Otherwise, it can be recuperated and accumulated for future usage.

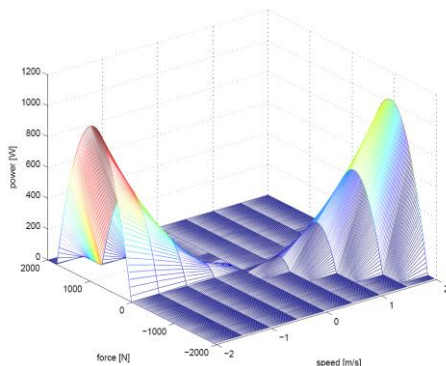


Fig. 3 Force-velocity profile of the recuperated energy of the used linear motor

In fact, there are some non-linearities in the recuperation process and that is why energy management is a bit difficult. The 3-D plot (shown in Fig. 3.) represents the force-velocity profile of the recuperated energy. It shows how much recuperated (and only recuperated) energy can be obtained under the given forces and

velocities. In the plot, when the recuperated energy is equal to zero it is necessary to supply the energy into the system. This characteristics surface gives a piece of important information regarding one of the requirements on the control system as the optimization objectives are equal to a maximization of the recuperated energy (with necessary trade-offs).

4. Controller

The controller for active suspension we designed [2] using H_∞ theory. The standard H_∞ control scheme is shown in Fig. 4. When the open loop transfer matrix from u_1 to y_1 is denoted as $Ty_1 u_1$ then the standard optimal H_∞ controller problem is to find all admissible controllers $K(s)$ such that $\|Ty_1 u_1\|_\infty$ is minimal, where $\|\cdot\|_\infty$ denotes the H_∞ -norm of the transfer function (matrix). For more information, see [2], [3]. The H_∞ controller is stated minimizing the $\|Ty_1 u_1\|_\infty$ -norm. In addition, it is possible to shape open loop characteristics to improve the performance of the whole system. For the active suspension system, the performance and robustness outputs should be weighted. The performance weighting has to include all significant measures as comfort and car stability (body speed, suspension displacement, actuator force, etc.). For the linear electric motor in the position of an actuator, an additional weight should be added to control maximum force, energy consumption, and robustness of the system.

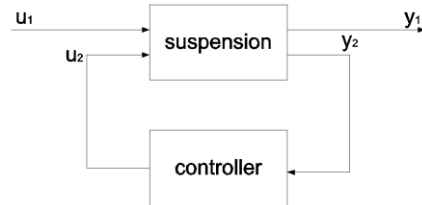


Fig. 4 H_∞ control scheme.

5. Quantification

Some quantitative measures have to be defined to evaluate the results achieved by the closed-loop system and to compare the active and passive systems.

Car Stability

The first requirement in the active suspension system is to improve car stability and “road friendliness”, that can be characterized as the attenuation of the tire pressure, or more precisely the attenuation of the unsprung mass force acting on the road. To get a measurable parameter, the following RMS function has been introduced:

$$J_{stab} = \sqrt{\int_0^T (z_w - z_r)^2 dt} \quad (1)$$

where z_w represents wheel displacement and z_r is road displacement.

Passenger Comfort

The second important requirement in the active suspension system is to improve passenger comfort. This requirement can be formulated as the sprung mass acceleration attenuation when the RM S function is defined as:

$$J_{comf} = \sqrt{\int_0^T G_w * \ddot{z}_b^2 dt} \quad (2)$$

where $\ddot{z}_b$ represents body acceleration; G_w is a weighting function for human sensitivity to vibrations and * denotes convolution.

4. Energy Control

The H_∞ controller has been designed using appropriate weights to optimize the minimum of the energy consumption with respect to the performance.

In the car, where the working conditions change according to the various drive situations it is very difficult (if possible) to say in general what level of performance is sufficient enough and how much energy can be obtained. It would be optimal to find a possibility of real-time control of energy consumption. The energy management is supposed to be controlled by an external signal depending on the car and road parameters, i.e. on the energy accumulator capacity and on the road surface, respectively. The first possibility consists in the analysis of the driving conditions and cyclic re-computing of the control signal in real-time. While the time requirements of the H_∞ controller design are too high (sampling period has to be less than 1ms!) and moreover the performance of the H_∞ controller cannot be guaranteed for all operating conditions this approach has been rejected. The second possibility is to control the energy consumption by controller deterioration. Then the designed H_∞ controller is reliably robust and the active suspension system is relatively stable. Let's assume two driving conditions:

- the terrain/surface the car is driving on is very rough and uneven and there is enough energy stored in the accumulator system - then the controller works in the standard mode, the motor consumes energy from the accumulator and the suspension performance is preserved.
- the terrain/surface the car is driving on is relatively smooth and there is not enough energy stored in the accumulator system because of the situation described above. The external signal provides the information to the H_∞ controller to deteriorate its performance and to reduce energy consumption. The deterioration is stated by the desired force attenuation.

If the force is attenuated too much then the active suspension system works similarly to the passive suspension and the linear electric motor works as a generator producing energy for the accumulator system. Of course, in such a case the suspension performance is deteriorated (to the passive suspension level in the worst case). The influence of these controller modifications to the suspension system performance is discussed in the section below.

The principle of the proposed energy management strategy is illustrated in Fig. 5. The H_∞ controller is extended by the variable gain block controlled by the external signal (energy management control input). In paragraph 4, energy management is discussed as an extension of H_∞ controller abilities. Now the influence on the performance and robustness will be presented. The H_∞ controller is deteriorated by the desired force attenuation using the input coefficient that is given by a superior controller.

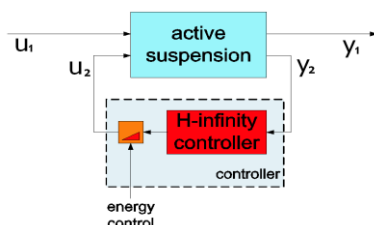


Fig. 5 Modified controller structure.

At first robustness tests have to be done to find the range of the input coefficient in the energy management block. To test robustness the direct numerical method has been chosen because the rank of the closed system is relatively small (4 for plant + 6 for weights = 10 for the system, 10 for the system + 10 for the

controller = 20 total for the closed-loop rank). Hence the poles have been tested for stability for a given input coefficient range.

The stability test in graphical form is shown in Fig. 6 and Fig. 7. In the figures, closed loop poles are plotted for the input coefficient range of $(-0.5 \div 1.7)$. Zoomed surroundings of the stability region from Fig. 6 is shown in Fig. 7. The original H_∞ pole placement is presented by *, pole placement for the stable region by #, and unstable region by ■, respectively.

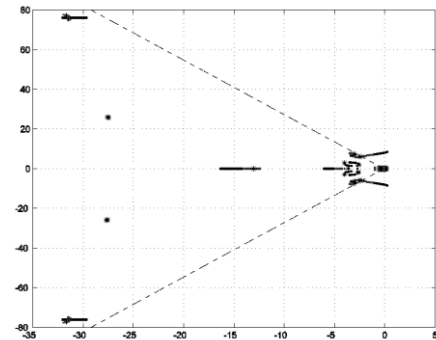


Fig. 6 Pole plot in energy control.

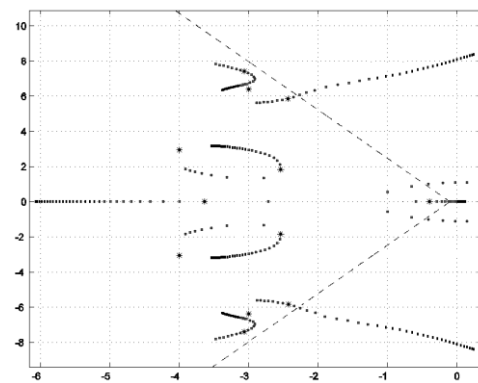


Fig. 7 Pole plot in energy control (zoom).

On the base of the test mentioned above, we have stated the maximum and minimum stable input coefficients. To achieve stability the coefficient must not exceed the range of $(0.000 \div 1.613)$.

The coefficient range should be determined to achieve also certain robustness. That is why we have chosen the pole region of relative damping 1.4 and maximum real part -0.1 as a condition. In Fig. 7, the selected region is represented by the dashed line. According to the previous section it does not have any sense to set the input coefficient greater than one. The resulting input coefficient range that satisfies the defined conditions is as follows:

minimum: 0.512; maximum: 1.000

At the end, the influence of the input coefficient on the active suspension performance has been tested.

The quantitative measures we have compared using passive suspension performance. The random road disturbance we have used as the first test input, and driving over a bump as the second input. The comparison for minimum and maximum input coefficients and their influence on the active suspension system performance is summarized in Table I [1]. The percentage values are computed as relative improvements of the active system compare to the passive suspension.

Table 1: Influence of Input Coefficient on Performance

	Coefficient 0,512	Coefficient 1
H_{∞} norm	0.455	0.359
Comfort	20.13%	29.89%
Stability	8.92%	12.83%
Energy	-71.1J	127.6J

6. Conclusion

In the paper, energy recuperation and management in active suspension systems with linear electric motors controlled using a proposed H_{∞} controller to obtain a variable mechanical force for a car damper has been presented.

The strategy for direct real-time energy management we have designed to decrease the energy consumption in the closed loop system. The method used modifies the standard H_{∞} controller and develops a stable controller with variable energy demands. All expected results have been tested in numerous experiments and simulations.

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INFLUENCE OF LIBERALIZATION ON LONG-DISTANCE RAIL TRANSPORT IN THE CZECH REPUBLIC

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Abstract: *In the Czech Republic, the rail transport market has been liberalized for several years - in addition to public services, commercial services of individual rail carriers operate too. Public services in long-distance rail transport are ordered by the Czech Ministry of Transport. In December 2019, the 10-year contract between Czech Ministry of Transport and Czech Railways will end. The approaching end of this contract was connected with great interest of other rail carriers, which led to the fact, that the Czech Ministry of Transport demanded individual long-distance rail lines in the form of so called "market consultations". Preparing of the operational performance of individual long-distance rail lines for the needs of market consultations was a great challenge on the field of transport-planning. As a result, from December 2019 there will operate 4 different rail carriers in ordered long-distance rail transport in The Czech Republic and this situation is unique in its form and unparalleled throughout the EU.*

Keywords: RAILWAY TRANSPORT, PUBLIC TRAFFIC, RAILWAY TECHNOLOGY, TIMETABLE DESIGNING, PERIODIC TIMETABLE, OPEN-ACCESS, CAPACITY, LIBERALIZATION

1. Order of public rail services in the Czech Republic

Since 2005, rail transport in the Czech Republic regionalised, 14 regions is responsible for ordering regional rail transport, the Ministry of Transport is responsible for long-distance rail transport order.

Public transport services in the Czech Republic are characterized by the fact that they represent in general a performance for which the sum of revenues is not sufficient to cover costs associated with the services.

Order of the Ministry of Transport is focused on the fixed interval connection between each regional capitals and other major residential areas in the Czech Republic.

Overall, in 2018 in the Czech Republic, the total volume of train-kilometers in ordered long-distance transport was about 35 million train km.

A feature of public rail services in the order of Ministry of Transport and the Regions is also the fact, that it is an "open" system, which works across the network unified fare system, so there is time, space and tariff interconnection of services. A feature of the system is not "denial of passengers" (i.e., inability due to lack of transport capacity of lines), while no reservations required (no link between a ticket and particular train). It is natural, that such a generally high quality parameters of public services cannot be met without compensation from national budget.

The total amount of payments from national budget for compensation for ordering of long-distance transport rail passenger transport was in 2018 CZK 4.1 billion (approximately EUR 158 million)

The main direct awarded 10-year public contract between Czech Ministry of Transport and Czech railways ends in December 2019.

2. The liberalization of the rail market in the Czech Republic

The current practice in the Czech Republic is still mostly represented in rail passenger transport services by direct selecting of the train operating company (TOC). In 2009, when Czech Ministry of Transport signed the 10-year contract with Czech Railways to provide transport services in long-distance traffic, followed extensive criticism from another TOC's. Czech private TOC's have criticized the closeness of the public service market and demanded public procurement for rail through transparent selection.

Before 2009, contract award after competition of TOC's was made on long-distance lines Pardubice - Liberec and Plzeň - Most. Both of these competitions were won in 2005 by Czech railways. Despite the victory of the national carrier, these competitions led to a reduction of compensation.

However, in 2009, there were timewise unable to prepare further competitions into the process.

Despite the fact, that the majority of transport volume in long distance rail transport has been selected directly, reported by the Czech Republic to support the liberalization of rail transport.

This declaration liberalization of passenger rail market has two specific implications:

- 1) official timetable for market opening in long-distance transport, the opportunity to compete in selected contracts
- 2) liberal access to railway infrastructure - Open Access

After closing of the 10-year contract between Czech Ministry of Transport and Czech Railways, the private TOC's in the Czech Republic focused on developing open-access services.

2.1. Open-Access in the Czech Republic

In the Czech Republic, additionally to the public services, there is a fully liberal approach to infrastructure – Open Access, without any restriction. Each TOC can apply to the transport infrastructure access authority (ÚPDI) and then may ask the infrastructure manager (IM) for capacity and IM (Railway Infrastructure Administration – RIA - SŽDC) will be required to allocate infrastructure capacity.

The first project in the Czech railway network, which had features of Open Access approach were the SC Pendolino trains between Prague and Ostrava. These SC-trains operate Czech Railways on their commercial risks, with mandatory reservation and limited passenger capacity and costs for transportation of these trains is significantly above the level of fares on trains, which are ordered and form a public service.

The second Open Access project are the Regiojet trains of (former) Student Agency company running on the route Praha – Ostrava – Havířov (- Žilina). Again, these are trains to TOC commercial risk, with mandatory reservation (seat reservation is included in the ticket), with limited passenger capacity, but the price for the carriage of these trains is comparable to fares on trains, which are ordered and form a public service.

The third Open Access project is a LEO Express, i.e. Leo Express trains again on the route Praha - Ostrava. As in the case of

Regiojet, in this case, the connections to the commercial risk of the TOC will have to provide mandatory seat reservation will have a limited capacity for passengers.

All Open-Access projects began to develop. Czech Railways, for example, has taken over the international night trains to their commercial risk. Regiojet expanded its activities to include connections Prague - Wien and Prague - Bratislava, Leo Express expanded its range of services to include connections Prague - Krakow and Prague - Staré Město u Uherského Hradiště.

This battle of TOCs in Open-access services is unprecedented in the European railway area. Already less than one year of sharp competition between three different TOC's has been indicated, that commercial Open-Access services are very unstable in time. Changing time position of the trains, changing and different stops, variable and unstable number of connections etc., such services cannot be reasonably operationally integrated into the open transport system and they can hardly serve as a fixed part of the territory's transport service.

2.2. Market opening in long distance transport

Market opening in long-distance rail transport should solve as a possibility to increase quality / price ratio in the Czech rail transport. Ministry of Transport expects, that the current level of compensation will be held and serve to reach higher quality or higher range of passenger rail services performance. A prerequisite is the case, it can maintain a stable long-term financing of the railway sector and there will be no significant changes in the amount of available financial performance.

After one-off competitions in the year 2005 (lines Pradubice - Liberec and Plzeň - Most) has the Czech Ministry of Transport already in 2011 published a schedule for market opening in long-distance rail transport. In March 2012 have been published specifications for the first competition (line Olomouc - Krnov - Ostrava).

Although the tender for the line Olomouc - Krnov - Ostrava was canceled for formal reasons in 2013, the competition trend continued. In 2014, the preparation of the tender for the line Plzeň - Most (where the contract from 2006 was to end in 2015) was launched. Due to procedural delays, the contract from 2006 was extended by 2 years - but the tender was in the end finally canceled on the basis of objections from Czech Railways. However, there occurred a breakthrough situation, when the Ministry of Transport used the possibility of direct awarding institute and assigned directly to the winner of the canceled competition (TOC GWTR) the operation on the line Plzeň - Most (with level of compensation offered in the cancelled tender). It was a clear signal sent to the market of rail operators, that the liberalization of the rail market would not be stopped due to procedural obstruction.

For a main contract with Czech Railways from 2009, which ends in December 2019, the Ministry of Transport prepared a follow-up of direct assignment of the contract. The rules for access to public services are laid down in the amendment to Regulation (EC) No 1370/2007, which is part of the fourth railway package. Applicability of direct award of the contract in the passenger rail services is in force to 25. December 2023.

However, as the private TOC's in the Czech Republic have announced their relevant interest for participating in long-distance rail-services, the Ministry of Transport has notified the order of long-distance after 2019 transport in the Official journal of the EU on a per-line basis, with a different duration, so that this corresponds to the published schedule for competitions i rail public services planned in years 2020 - 2034.

3. Procedure for concluding new contracts after 2019

The Ministry of Transport access is clear that the priority-driven process in which is preserved the networked public rail transport (in Czech and Central European scale) and will clearly set in advance in market access conditions, including rules on mutual recognition of travel documents and the use of station buildings.

The principle is, that the Czech Ministry of Transport published in spring of 2017 in the Official journal of the EU, that all long-distance lines from 12/2019 will be reassigned. Each line had its own notification - all as a direct allocation for CD.

Until spring 2018 have The Ministry of Transport negotiated with Czech Railways, what transport parameters (vehicles, performance quality, timetable) of which lines is possible to offer for next contract period.

Approximately in March / April 2018 got The Ministry of Transport offer from Czech Railways on all lines and additionally also offers on some lines from another TOC's.

Than was necessary to sort, on which lines are the offers of another operators more favorable, than the offer from Czech railways. Because the third operators have not previously negotiated with The Ministry of Transport, were the offers not comparable. The Ministry of Transport has then made operational "packages" and asked with these packages new request to all interested TOC's (including Czech Railways) - for to update offer specification.

Content of each operational "package" was line (or more lines) with such timetable and quality requirements, which was negotiated with Czech Railways between 2017 - 2018. So the assignment of each package was always direct assignment - only based "market consultation". The requests to TOC's for offers for operating these "package" - so called "shoot-out" - ran between June - November 2018.

3.1. Technological structure of operational "packages"

In order to formulate the content of each operational package, it was necessary to set their structure, in particular the operational closeness and consistency.

A task was the basic determination of number of trains and their position in nodes (marketing timetable), defining the size of train-sets including regular and seasonal capacity strengths and timetabling (calculation of travel times).

Existing interconnected traffic provides a variety of synergies (typically vehicle-to-line transitions) and it was not desirable to lose these benefits.

For the operational separation of the lines and the arrangement of the operating structure of the packages, it was necessary to reflect the number of vehicles in relation to the timetable. On the operational side, such lines were grouped into individual packages, taking into account the operational background, necessary transport capacities and traction.

From the timetable point of view, it was often necessary to add new connection or links, for to isolate individual packages and close them to the functional cycles. In this step, it was necessary to reflect IPT nodes, bindings and schedule boundary conditions, transfer / changing nodes and intended length intervals for peak-and-off-peak hours.

The author's team used their previously published approach, which combines timetable proposal and operational concept with cycles of vehicles, in mutual repeating iteration steps.

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 peak hours and minimizing the number of vehicles in peak period; ideally for the number required in previous point 1

3) operational optimization and ensuring operational efficiency (refueling, maintenance, cleaning...)

4) adaptation of timetables in the evening hours (to minimize the number of vehicles, reduction of total working times)

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

4. Conclusion

Based on so operationally and transportly defined content of packages were made so called "shoots" - every interested TOC gave its offer to the Ministry of Transport.

As first package, there was already in June 2018 direct assigned a package including a line Pardubice - Liberec. The winner of this "shoot-out" was Czech railways.

As second package, there was direct assigned a package including lines Praha - Olomouc - Žilina and Praha - Olomouc - Luhačovice. The winner of this "shoot-out" was Czech railways too.

As third package, there was direct assigned a package including line Brno - Bohumín. The winner of this "shoot-out" was Czech private railway operator Regiojet.

As fourth package, there were direct assigned a package including large network of fast trains in diesel-traction in middle Bohemia (Praha - Tanvald, Praha - Rakovník, Praha - Písek - České Budějovice, Kolín - Nový Bor). The winner of this "shoot-out" was international operator Arriva.

Market opening in long-distance rail transport should solve as a possibility to increase quality / price ratio in the Czech rail. The whole money, which was saved by "shoot-outs" of these packages, will be from December 2019 inserted in broad timetable extension - and not only on the lines included in these packages, but nearly on all lines in the fast-train network.

This way of liberalization of public rail services using direct assignment has currently in Europe no analogy. Although there has been a clear commitment to a functional operational arrangement, it will be exciting to see, how this system will work in practice, with the launch of a new timetable in Dezember 2019, and above all, how passengers will react to this new system. A major challenge will be the coordination of individual transport services in operation to maintain the functionality and integrity of the rail transport system.

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FIRST AID TO THE VICTIMS OF ROAD ACCIDENTS IN THE EVACUATION PROCESS

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Abstract: The statistics demonstrate that giving the qualified first aid at the scene before admission is significantly less frequently than would be expected.

Medical care at the pre-hospital stage is of particular importance in cases of manifest circulatory and respiration disturbances, clinical death, bleeding, fractures, when a failure or delay to render assistance quickly leads to a significant deterioration of the body condition and even death.

The majority of the victims die at the pre-hospital stage, resulting in high importance of qualified first aid in the first moments after injury.

KEY WORDS: ROAD TRAFFIC INJURIES, URGENT CONDITIONS, RESUSCITATION.

1. Introduction

The intensive development of transport communications has exacerbated the problem of conflict with human flows in modern society. Vehicles are distinguished by high power and speed. The dynamics that accompany this development had naturally led to a significant increase in trauma in people, the cause of which is a conflict with the traffic flows. In recent years, among the causes of mortality of people aged 5 to 45, road accidents ranked second [1].

In modern conditions, road accidents are characterized predominantly by pelvic fractures, in combination with head segments injuries and other bodily injuries. Soft-tissue damage and ligamentous apparatus injury are often overlooked; attention often is not paid to hidden injuries. In addition, the statistics demonstrate that giving the qualified first aid at the scene before admission is significantly less frequently than would be expected. For example, first-aid assistance is provided by employees of the road patrol service only in 1% of cases; assistance from the fellow travelers or from drivers and travelers of other vehicles is provided in 10% of cases. The reason for this is primarily a low level of skills of first medical aid to people found at the accident site.

Numerous researches and tests have revealed that at a frontal collision of the adapted bus, the angular speed and acceleration of head of a traveler with restricted mobility, which is much larger than of a common traveler, causes closed trauma, while at a "collision from behind", cervical vertebrae are mostly damaged. Therefore, during such road accident, it is necessary to take into account the specificity of the mentioned injuries, as well as the administration of first aid.

In the evacuation process from the accident site, the rapid administration of first aid is of particular importance. In cases of manifest circulatory and respiration disturbances, clinical death, bleeding, open and closed fractures, thermal and chemical burns, delay to render assistance quickly leads to a significant deterioration of the body condition and even death.

Statistics confirm that the mortality rate in road accidents is as follows: 50% of victims die in the first seconds and minutes of accident, 30% of them lose their lives during the first two hours after the injury, and 20% of victims - 5 days after. From this data, it clearly appears that many victims of road accidents lose their lives at the pre-hospital stage. More than half of them die at the accident site before the arrival of a medical emergency team, which emphasizes the importance of medical assistance from the first moment after the injury.

According to the official statistics, more than 40 000 road accidents occurred in Georgia in 2018. More than half of those who lost their lives in road accidents are people of active working age from 22 to 40. More than 20% of the injured are maimed. 9047 people were injured in road accidents occurred in 2018, and 459 people lost their lives. Of these, 13 were children under the age of 7. According to the 2018 statistics, the number of road accidents

increased by 6% compared to the previous year, followed by the increase in the number of the injured people.

The reasons for accidents with fatal consequences are as follows:

- 27 % - of the rules for maneuvering;
- 26% - speeding;
- 19% - swerving into oncoming traffic;
- 9% - driving under the influence of alcohol;
- 19% - different violations.

The mortality rate among children in road accidents is 4-6 times higher in comparison with the Nordic and economically developed countries of Western Europe. According to expert estimates, a significant number of victims lose their lives because of incomplete and delayed medical care, although injuries sustained in road accident were not fatal [2]. Lethality of injuries sustained in road accidents largely depends on the level of preparation of specialists of an ambulance team, their skills to persons under life-threatening conditions, as well as on the proper organization of life-saving and anesthesiological treatment at the scene and in the evacuation process [3].

Experience gained in clinical practice in the world has clearly demonstrated the important parts of these problems that have not yet been resolved so far: belated diagnosis, imperfect assessment of the severity of injuries sustained in road accidents, high frequency of complications, high rates of injuries, the predominance of injuries among people of working age. Most of the severe consequences can be explained by belated and inadequate diagnosis. Experience has shown that in the case of polytrauma, the medical staff cannot reveal injuries in a timely manner, which leads to the post-complication development and prolonging the treatment duration, and often to patient's disability or fatal localize. During polytrauma, there is a variety of the injuries localization and severities, as well as a multitude of their possible combinations for the victims.

The complications of polytrauma diagnosis caused in road accidents are caused by their pathogenesis, which often leads us to typical symptoms that ultimately translate into diagnostic pitfalls. This is due to the fact that polytrauma sustained in road accident is characterized by a number of peculiarities: there is exhibited a syndrome of mutual complication of factors affecting the process; often the process preceded by the less severe symptoms, but with more pronounced pains. At this time, they eliminate the symptoms of the main damages, which call an urgent operational intervention. Many experts believe that there are distinctive features of polytrauma:

- Syndrome of mutual aggravation;
- Atypical symptoms that complicate diagnosis;
- High likelihood of the development of traumatic shock and massive loss of blood;

- Instability of the compensation mechanisms, and a large number of complications and fatalities.

Characteristic features of the assistance to the victims of road accidents are represented by the reconciliation of the diagnostic process and the immediate elimination of significant injuries. Among them, the priority is given to the emergence evacuation victims to hospital; the measures slowing the evacuation process are undertaken only in accordance with vital indications. In addition, it is necessary to strictly adhere the algorithm for action, which can lead to serious diagnostic errors. First of all, this is the assessment of the life-threatening disorders of the victim's respiratory and circulatory systems.

Decision on the time of transportation of victim is made in accordance with the life-threatening disorders, which is required for transferring patient the clinic. In case of the need for undertaking medical reanimation measures, transportation can only be possible after overcoming life-threatening situation [5].

2. Preconditions and means for resolving the problem

Primary medical examination (not more than three minutes):

1. Signs of respiratory distress: strongly-marked cyanosis, futile attempt to breath in, chaotic arrhythmic breathing, inclusion of auxiliary respiratory muscles.

Primary cause – full or partial obstruction of respiratory tract. In an examination, it is necessary to exclude severe breast damage through auscultation: open or pressure pneumothorax, hemothorax, breast damages.

2. Hemodynamic assessment: it is necessary to measure heart rate and blood pressure. The clinically significant tachycardia that requires therapeutic intervention, among under 1 year old children, is 220 bpm, among older children - more than 200 bpm, bradycardia among under 1 year old children - less than 60 bpm, among older children - less than 50 bpm.

Systolic pressure for children aged 1 year up can be calculated according to the formula: $90 + (2 \times \text{age in years})$. Hypotension among under 1 year old children is considered to be a reduction in systolic pressure up to 70 MmHg, and among children aged 1 to 10 - $70 + (2 \times \text{age in years})$, for children aged 10 year up - less than 90. The pulse can be checked on a radial artery, if the blood pressure is greater than 80 MmHg, on a femoral artery - > 70 MmHg, on a carotid artery - > 60 MmHg. For babies, it is recommended to check the pulse on a brachial artery, and for older children - on a carotid artery [3].

Bradycardia itself does not provide adequate perfusion, so the treatment of deep bradycardia should be carried out in the same way that treats asystolia.

1. Cardiopulmonary resuscitation

During the primary medical examination of the victims of road accidents, special attention is paid to the signs of clinical death and/or circulatory deficiency: pulselessness on the major veins, the absence of spontaneous breathing, status of pupils, the absence of heartbeats, considerable bradycardia (heart rate below 60 among under 1-year-old children, and below 50 bpm, among older children, in case of the presence of circulatory failures).

The first stage of cardiopulmonary resuscitation involves:

- unblocking airways;
- breathing management and lung ventilation;
- preservation of blood circulation and stopping bleeding.

These factors in the process of cardiopulmonary resuscitation are often denoted by the ABC abbreviation.

1.1. Airway breathing

In order to ensure airway breathing, it is necessary to open the victim's mouth. If clotted blood or foreign body were lodged in the victim's esophagus, it is necessary to clean up by means of the aspirator or napkin. If obstruction is caused by tongue, it is necessary to put the lower jaw forward. If the patient is unconscious, then it is possible to install the S-type air duct in his/her body. The dimension of this air duct should be adapted to the patient's age. The triangular method of covering (pushing back the head, opening the mouth and putting the the lower jaw forward)

is considered to be the best method of post-traumatic recovery of airway breathing [6]. However, if there the reason to believe that the backbone neck section is injured, then the victim's head should be pushed back not too far. In such a case, the head is pushed back moderately (by stabilizing the neck section).

2. Pharmacological therapy

1 If there were signs of cardiac deficiency, the drug to be chosen is an adrenaline (epinephrine). It is injected intravenously or into the bone. The dosages are shown in Table 1 [3].

Table 1.

The doses of adrenaline for patients injured in road accidents

Patient's weight, kg	An initial dose for intravenous and intra-bone injection	The second and further injection doses
10	0,1 mg 0,1 ml (1:1000)	1–2 mg 1–2 ml (1:1000)
20	0,2 mg 0,2 ml (1:1000)	2–4 mg 2–4 ml (1:1000)
30	0,3 mg 0,3 ml (1:1000)	3–6 mg 3–6 ml (1:1000)
Adults	1,0 mg (standard dose)	Variation is provided

It should be noted that in the resuscitation process, adrenaline can be administered in every 3 minutes before the heart rate is recovered.

After injecting any drug into the peripheral vein or bone, it is necessary to immediately introduce 5-10 ml of isotonic solution, in order to accelerate inclusion of drug into the central circulation [7].

If it is not possible to enter the venous or intrabone channel, and there is a need for injecting the drug externally, there is used the intratracheal method of drug instillation: into the endotracheal tube (if intubation was performed). At this time, the drug is doubled and dissolved in 1-2 ml of physiological solution. The total volume of one-time injected drugs can reach from 20 to 30 ml. Adrenaline intake in the heart is used only when it is impossible to treat by other methods.

In case of urgent need, prior to intravenous injection, we can apply the method of sublingual injection of drug (into the muscles of mouth cavity), which allows for urgent intravenous injecting of the required drug dose, since there is no time for venous puncture.

In this case, there is used the Three Deuces rule: the drug is injected 2 cm from the front of chin, by means of the intramuscular injection needle at a depth of 2 cm in sublingual muscles in the direction towards the crown, the total volume of which does not exceed 2 ml (1 ml for children of up to age three). The drug dose should be standard, without dilution.

The effectiveness of heart function for kids is mostly by frequency of the pulse, so during bradycardia, it is treated as in the case of asystolia. Along with adrenaline, there may also be selected the atropine. It is administered by intravenous, intraosseous or endotracheal injection at a dosage of 0,02 mg/kg, approximately 0,1 ml per year of child's age, but no more than 0.6 milliliters. In endotracheal injection, this dose is doubled. In case of a low effectiveness, the repeat dose can be given to patient in 3 to 5 minutes. In the cases of prominent ventricular tachycardia or fibrillation, the drug to be selected is lidocaine on 1-2 mg/kg (intravenous, intraosseous or endotracheal) in every 3-5 minutes up to the total dose (on 3 mg/kg).

3. Infusion therapy

Severe trauma is always accompanied by a shock complication, so at the pre-hospital stage, it is necessary to provide intravenous or intrabone injection of liquid. For this purpose, there is mostly used by the Ringer's balanced salt solution. At the initial stage, it is injected at a dose of 20 ml/kg. Infusion is also done at the rate of normal blood pressure.

The second bolus of infusion is repeated with the same dose, and if the first bolus does not improve signs of tissue

perfusion disorder: the light colored skin, capillary time ("white spot") increases over 2 seconds.

If in the case of detecting the symptoms of internal hemorrhage (suspicion of fracture of the pelvic and the long bones, for intraperitoneal hemorrhage, it is expedient to initiate infusion with colloidal solutions, among which the most recommended in the pediatrics is hydroxyethylated starch 130/0,4, which can be injected at a dose of 20 ml/kg. It has minimal side effects [3].

The next stage is a crystalloid infusion. There has been confirmed the prospect for the use of method of a low-volume infusion of the hypertonic solutions of sodium chloride at the victim evacuation stage. Also, there have been registered the drug of a mixed composition – Hyperhaese, which includes hydroxyethylated starch 200/0,5 and a sodium chloride 7.2%-solution. The maximum volume of its injection dose is 4 ml/kg. The anesthesiologist-reanimatologists of the pediatric field have justified a high effectiveness of using Hyperhaese at the evacuation stage, when providing the first aid to children injured in road accident.

4. Analgo-sedation

Specific requirements are applied to analgetic and sedative methods and agents for the victims of road accidents. They should be distinguished by the technical simplicity, high effectiveness, fast pain medication, they should not have a depressing effect on the life-saving systems. Of these drugs, an ambulance team must have a non-narcotic metamizol (analgin), which must be injected into the vein or bone with a dose of with a dose of 1 mg/kg. If it is impossible to inject this drug into the vein or bone, it can be injected into the muscle at a dose of 4-5 mg/kg, but in this case its action will start 4-5 minutes later. For sedation, along with these analgesics, there are also injected into the vein (bone) diazepam (seduxen, rilanium) with a dose of 0,3 mg/kg, or into the muscle, at a dose of 0.5 mg/kg. Narcotic analgesics - morphine or promedol - are allowed for newborns with a dose of 0,1 ml/per year, but not more than 1 ml, phentanyl, at a dose of 2 ml/kg. The narcotic analgesics are used with analgin. A good effect is produced by the use of different blockings with local anesthetics.

5. Medical care in the process of evacuation of victims

Before we start the victims evacuation process from the accident site to the hospital, it is necessary:

- to undertake all preparatory and preliminary measures required for transportation (preparation of victim and vehicle, providing opportunities for injections, sanitation of the mouth cavity, esophagus and trachea, as well as conducting oxygenotherapy and so on);
- to maintain all conditions for proper transportation for a particular victim, in accordance with the severity level of his/her state, taking into account the major pathological syndromes (monitoring of vital functions of body, conducting the infusion therapy, readiness for cardiopulmonary resuscitation, providing artificial lung ventilation and so on);
- to pay special attention to the persons with restricted mobility in the adapted bus, since in road accident, they are mostly injured in the head and neck areas, which is not visible during the visual inspection. Therefore, their above mentioned organs must be fixated, so that their state won't become even more severe in the transportation process.
- to determine the complex of those treatment measures that are necessary in the transportation process of the victims (infusion therapy, artificial lung ventilation, the use of medicines for the preservation of vital functions, and so on).

Prior to the start of transportation, the victims will be provided with additional rapid physical examination of:

1. Head - skull bones and tissues, facial skeleton, eye damage, hemorrhages, liquorrhea;
2. Neck – subcutaneous emphysema, trachea and backbone neck section damage;
3. Breast bones – respiratory excursion, asymmetry, breast skeleton damage;

4. Abdomen – we need to remember that in case of injury caused by a sharp object, there are often damaged liver and kidney, which leads to intra-abdominal hemorrhage;

5. Extremities – to assess the voluntary movements;

6. Skin – damage detection;

7. Additional neurological examination.

When starting the transfer of victim and during the transportation process, it is necessary to maintain systolic blood pressure at 90 MmHg (80 MmHg for children of up to age three), and the pulse rate should be within the 10%-deviation limits, according to ages. Arterial hypertension should be eliminated as soon as possible. In the case of hypertension maintenance and intravenous or intra-bone active infusion therapy in the form of constant infusion, there are used injection of dopamine with an average dose of 6-8 mkg/kg/min. For this, 0,5 ml of a 4%-dopamine solution is dissolved in 200 ml of physiological solution, and there is carried out drip titration under blood pressure control. If there is no dopamine, there is used adrenaline with a dose of 0,1 - 0,5 mkg/kg/min. In this case, 1 ml of a 0,1%-adrenaline solution is dissolved in 200 ml of physiological solution, and titration is carried out in the same way as with dopamine.

3. Conclusion

A large number of complications and fatal consequences are associated with the belated delivery of the victims of road accidents to the hospital (the "golden hour" rule), insufficient fixation of fractures, belated diagnosis and operative treatment of all injuries, inconsistencies between the adequate rehabilitation and out-of-hospital care.

The inevitability of road traffic injury conditions the need for developing the uniform tactics of providing assistance to the victims. Under great pressure of time, one of the methods for excluding diagnostic and medicinal errors for the victims injured in road accidents is a reasonable use of the algorithm and treatment schemes for providing medical care. The right treatment-diagnostic tactics by an ambulance team, timely hospitalization of victims with providing the medical care at the accident site and during the transportation process, as well as continuous retraining of medical personnel for improving their practical skills, pertain to the reserves in combatting the grave consequences of road accidents.

The use of the correct algorithm for providing medical care to the victims of road accidents, dynamic observation and continuity in the stages of treatment contribute to improving the health quality by general and individual criteria (physical strength, positive emotions, activity, workability, and fulfilling life in a social environment).

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TRANSIT CAPACITIES OF THE SOUTH CAUCASUS TRANSPORT CORRIDOR

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Abstract: *The volume of trade between East and West of the Eurasian continent takes place on the numerous routes. However, the Europe-Caucasus-Asia (TRACECA) transport corridor is most known to the world community.*

The TRACECA program projects involve the integrated development of sea, railway and road transport. As the consolidating measures, the central concern is the unification of transport legislation of the participating countries, the liberalization of regulation of shared services, the solution of common market and social problems in the area of the environment, security and international integration.

Time of delivery, as well as transportation costs through the Europe-Caucasus-Asia corridor depend upon the successful solution of these challenges.

KEY WORDS: RAIL FERRY CROSSING, MULTIMODAL TRANSPORTATION, LOGISTICAL SUPPORT.

1. Introduction

All transit routes that provide traffic flows by land, maritime and in the mixed form, play a crucial role in trade and economic relations between Europe and Asia. Over 50% of world traffic flows goes to the carriage of goods between West and East.

Georgia is located in the most important and sensitive geopolitical regions of the world, in key location of the Great Silk Road that historically played a huge role in the development and relations of Europe and Asia. Since late last century, due to its own geographical space, historical past, political significance and economic capacity, Georgia has become a new geo-economic center between Europe and Asia, as well as between Russia and the Middle East. Consequently, a growing interest has emerged in Georgia as a new center of geo-economic attractiveness in regional and international arenas. The main geopolitical task of the country is integration into the European structures. Thus, the geopolitical strategy is clearly declared, and for the creation a niche for itself in the world economy, of utmost importance is to formulate and implement a well-constructed geo-economic strategy in relevant cooperation with local and international allies in the region. Thus, Georgia's geo-economic positions are influenced by: the intraregional level players (Armenia, Azerbaijan); in the case of the interregional level - Russia, Turkey, Iran, Central Asia countries; and such international level players as the EU, the United States and China.

At the current stage, in the context of globalization, the geo-economic role of Georgia, as a significant transit artery linking the west and the east, north and south, becomes all the more relevant and takes place in the geo-economic interests of big countries, such as the USA, EU member states, China and neighboring states. This transit artery is also important for the economic interests of Central Asia countries. Thus, the geo-economic positioning of Georgia has turned Georgia into a global interest. The developed countries have started to actively cooperate with Georgia in order to maximize their advantageous geo-economic significance.

In the center of the Caucasus transport corridor, the railway line running through the territory of Azerbaijan and Georgia connects the port of Baku in the Caspian Sea with the Black Sea harbors in Batumi and Poti. Not so long ago, this line could pass 40 pairs of trains per day, was considered well-equipped and electrified. However, the modernity has demanded reconstruction of this and other rail routes. For example, Azerbaijan, on the basis of free technical and financial assistance from Europeans, was able to repair and reconstruct two large bridges on the state railway, carry out major repairs of the track in some sections, as well as to buy boiler installations for steam cleaning oil tankers, purchase spare parts and so on. Within a short period, the country also succeeded in creating its own base for major repairs of locomotives, freight and passenger stocks.

Some projects are based on foreign loans. In Azerbaijan, over \$ 20 million from funds at the European Bank for Reconstruction and Development was used for reconstruction of the railway infrastructure, and in Georgia, the refurbishment of railways and roads was carried out within the World Bank project (\$ 11 million).

In order to ensure the reliable transmission of information on the transportation of goods, the fiber-optic cable was laid along the Baku-Tbilisi-Poti-Batumi railway. The work was carried out under the TRACECA program, and \$ 15 million was spent on it.

2. Preconditions and means for resolving the problem

On the Caspian, one of the most important transport hubs of the route is the Baku International Sea Port. It has several mechanized berths that specialize in working the cargo and tank vessels, as well as ferries and high-capacity containers. With the aid of the grant, the port has purchased the modern cargo-handling equipment. Rehabilitation of port using foreign investment is under way.

In the east, within the TRACECA projects, the great bulk of the cargo from Baku was to be transported by ferry across the Caspian Sea to the far bank into the port of Turkmenbashi. Then, the goods were to be transported through Turkmenistan by rail or motor road. In recent years, humanitarian aid and goods have gone on this route for economic recovery of Afghanistan. However, the peculiar position of the leadership of this country in relation to the transportation of goods, and the unpredictability of its position have generally forced to search for alternative routes. This has become the route of the north-east direction towards a new and rapidly developing Kazakh port of Aktau. It was rehabilitated in a short time with funds from EU, and this made it possible to significantly increase the volume of cargo and passenger traffic through the territory of Kazakhstan.

In the west, the Caucasian transport corridor is also divided into the separate directions. The railway ferry service linked the Georgian port of Poti to the Ukrainian port of Ilyichevsk and the Bulgarian port of Varna. The European Union had to spend The European Union had to spend more than 13 million euros on the creation of a triple railway ferry link Varna-Ilyichevsk-Poti / Batumi.

With increased cargo traffic, it is possible to open railway ferry link to another Bulgarian port - Bourgas. Both Bulgarian ports are well equipped, and they can receive and store the increasing volumes of cargo, are linked by rail and motor roads to the most important business centers of Europe.

According to the tripartite agreement between Bulgaria, Georgia and Ukraine, the goods passing through their ports were dispensed from paying the state duty.

The absence of a railway line to the east from Batumi and Poti through Iran increases the importance of the motor road going in the same direction and not crossing Azerbaijan and Turkey. A project was proposed to transform the Armenian section of this road into a highway. Thanks to flattening, the length of the road will be noticeably reduced.

Azerbaijan and Georgia are also engaged in improving their roads. The idea was put forward to build a toll Transcaucasian highway Tbilisi-Baku, which will allow for reducing significantly travel times from the Black Sea coast to the Caspian Sea.



Fig.1. The Eurasian central transit routes

Georgia has access to Europe by land and sea routes. The land route is part of the Trans-Caspian international transport route (the middle corridor in Fig.1.). This route combines the Baku-Tbilisi-Kars railway with the Yavuz Sultan Selim bridge over the Bosphorus Strait. The Baku-Tbilisi-Kars railway is a transport corridor linking the railway networks of Azerbaijan, Georgia and Turkey. It was opened on October 30, 2017. The projected traffic for this route is 10 million tons, with a possible (theoretical) increase up to 20 million tons [1]. The sea route can serve as a way out to Europe through the Black Sea ports in Batumi, Poti and Anaklia. Currently, there are three ports in Georgia: Batumi, Poti and Kulevi. There is also a cargo terminal with liquid in Supsa. However, the depth of the existing ports is insufficient to receive medium-sized cargo ships or large carriers of crude oil. To deal this constraint, the government of Georgia has decided to build a deep-water port on the Black Sea coast in Anaklia. The depth of the seaport is 20.5 meters (in Batumi - 14 meters, in Poti - 8.5 meters). The port of Anaklia will be able to receive large-sized ships of the Panamax and Postpanamax classes with a loading capacity of 50–150 thousand tons [2]. It is expected that the new port will become one of the main logistics centers in the South Caucasus and one of the main sea gateways for Georgia. The expected throughput of the port should reach 100 million tons per year [2].

Petroleum pipelines Baku-Tbilisi-Ceyhan and Baku-Tbilisi-Supsa, as well as gas pipeline Baku-Tbilisi-Erzurum are routed via Georgia, and Georgia is active in TRACECA (Transport Corridor Europe Caucasus Asia) and INOGATE (Interstate Oil and Gas Transportation to Europe) projects.

TRACECA is a program of international cooperation between the European Union and the partner countries on the organization of the Europe-Caucasus-Asia transport corridor. An important role in TRACECA is played by Georgian Railway JSC, which transports both liquid and dry cargo. Liquid cargo, consisting of crude oil and petroleum products, amounted to 46% of total goods traffic in 2016, while transit shipment - about 52% [3]. INOGATE is a program of international cooperation in the energy sector between the European Union, the Black Sea and Caspian states, as well as with their neighboring countries. The program was founded in 1996, and it is being implemented on behalf of the European Union [4]. For these pipelines and programs, an appropriate infrastructure has already been created, which can be used for the Belt and Road initiative.

Georgia has the free trade agreements with both EU and China. The Free Trade Agreement, signed in May 2015 in Beijing, entered into force on January 1, 2018. Prior to that, in 2014, the Deep and Comprehensive Free Trade Agreement (DCFTA) was signed between the European Union and Georgia, which has been entered into force since 2016 [14]. Georgia has also signed a Free Trade Agreement with Hong Kong. This Agreement was mutually agreed in 2016, and it has several standard components, particularly: elimination or reduction of tariffs; liberalization of non-tariff barriers; flexibility regarding the rules of origin to facilitate bilateral trade; procedures for simplifying customs procedures; investment liberalization, promotion and protection; liberalization of trade in services and the dispute settlement mechanism for a free-zone trade [5].

In recent years, the bilateral relations between Georgia and China have made rapid progress and obtained the positive results. Georgia positively considers the Belt and Road initiative, and wants to strengthen the cooperation with China in various fields.

3. Conclusion

The analysis of the main challenges and development opportunities of transport and logistics in Georgia indicate the need for developing a single state strategy and a single legal regulatory mechanism in this field, within which, it will be possible to demonstrate the capacities of the overall transport logistics system. In addition, full implementation of the transport and logistics potential of Georgia is associated with the analysis of the following issues in a common format: raising the quality of coordination between the individual government agencies; contribution to the development of a competitive environment among the carrier business operators; facilitating the implementation of a common tariff policy on cargo traffic; amendments to be implemented in the tax and free industrial zones regulatory legislation in Georgia; activating economic diplomacy; improving the administrative, technological and information space of transport and logistics infrastructure and services.

The Belt and Road initiative contributes to the economic development of many countries. Georgia expects that this initiative will lead to an increase in transit shipments and a remarkable recovery of the national economy. In general, the Belt and Road initiative is beneficial both to Georgia and China. In this context, the governments of both countries should make every effort to further deepen their cooperation. Georgia has a chance to serve as a

link between Europe and Asia and benefit from its geographical and geopolitical position.

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INCREASED RISKS OF IMPACT ON THE ENVIRONMENT OF POTI AND KULEVI SEA PORTS

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Abstract: Based on the status of the maritime country of Georgia, we studied the increasing risks of the pollution by the ballast water and wastewater volume increase in the sea caused by the volume of freight turnover of Poti and Kulevi sea ports. For this, we conducted research in two directions: on the sensitive areas of Kulevi and Poti pipeline terminals and ships in the port. We first examined ecological parameters: namely water relative temperature, water acidity (pH) and salinity (TDS) quantitative indicators as in the stationary, also in non-stationary conditions. The results of the laboratory survey of water samples indicate that the relative temperature (t1 / t2) of Poti (t1 / t2) 0,87 acidity (pH) 8,34, salinity (TDS) 15,60 Relative temperature of turbocharging (t1 / t2) 0,87, acidity (pH) 8,37, salinity (TDS) 15,12 Secondly, on the ships entered in the ports, we took as ballast and wastewater samples and analyzed in accordance with the legislation:

1. Ballast water analysis from tanker "Metin K" from Kulevi, shows that increased nitrogen +6 mg / l, oilseeds +0.7 mg / l, nitrates 1,3 mg / l and nitrites- 0,35 mg / l

2 Poti Port - N 5 Ventilation Examples of Weight Watchers Examples of Weighted Particles 4.0 mg / l, Ammonium 1,67 mg / l of ballast water analysis shows that the total amount of oil nitrogen is 0.6 mg / l, + 0.7 mg / L, nitrates 1,3 mg / l d nitrites - 0,35 mg / l.

As a result of these two studies, based on reliability and risk theory of Kulevi, the mean value of salinity (TDS) is equal to: 10,85, for Poti port, the mean value of salinity (TDS) is equal to 12,34.

In the theoretical and laboratory studies we have identified the risks of contamination of ports and waste water pollution.

KEYWORDS: WASTEWATER, BALLAST WATER, RELIABILITY, RISK.

1. Introduction

The transport infrastructure of Georgia is unimaginable without the development of marine ports, especially for the sea ports of Batumi, Poti and Kulevi. They have a crucial role in shipping of marine cargoes. The development of ports should be proportionate to other transport infrastructure of Georgia. Therefore it is necessary to develop a scientifically justified program for the development of Marine Infrastructure of Georgia, which once again indicates the goal of our research to study the risks of polluting the pollution of the Poti and Kulevi sea ports by increasing the volume of cargo turnover.

2. Preconditions and means for resolving the problem

It should be noted that the necessity to provide ecological safety of marine ports under the strategic direction of the country, located on the Black Sea, which is directly related to the scientific study and prediction of the ecological problems of the Black Sea. In addition, as it is known, the ecological environment of the Black Sea depends mainly on the amount of oxygen (%) and bacteria, salinity (TDS), water acidity (pH), air (t1) and sea temperature t2 (C0). Special attention should be paid to the study of the number of oxygen in the vertical layer of the sea (depth 100 m), where the photosynthesis process is active and promotes the viability of the flora and fauna. Taking into consideration all this, the scientific research of the Black Sea ecological issues and its prediction allows us to evaluate the main ecological parameters in the Black Sea, specify their quantitative and qualitative characteristics, new vulnerable areas of the sea coast, which at the next stage will allow us to fully evaluate the Black Sea ecology problems and ecological safety measures of coastal areas and surrounding areas are planned.

In the theoretical study of the thesis the study of the main ecological parameters of the Black Sea are presented. The use of conducted studies in practice will enable us to assess the ecological security of Kulevi and Poti ports and adjacent territories located within the boundaries of Georgia, which is one of the main strategic and economic priorities of Georgia's economic and social development. We conducted surveys in two directions: on the sensitive areas of the Kulevi and Poti pipeline terminals and ships in the port.

The aim of the first research carried out in 2015-2017 was to take samples of water samples in the seaside zones and measuring the main parameters:

1. Fixing the water (t1) and air (t2) temperature;
2. Water acidity (pH);
3. Determination of quantitative indicators of salts (TDS).

First of all, on ships arriving in ports, we took as ballast and wastewater samples and analyzed in accordance with the legislation:

Table 1. Analysis of Ballast Waters from the Tanker – "Metin K" in Kulevi Port

N	Showings	sample	Norm
1.	Oxygen dissolved in water	8,1 Mg/L	6,0 Mg/L
2.	pH	7,9	6,5–8,5
3.	Salinity	15,9 Mg/L	19,0–22,0‰
4.	Weighted particles	2,0 Mg/L	30 Mg/L
5.	copper	0,9 Mg/L	0,001 Mg/L
6.	Iron	0,06 Mg/L	0,005 Mg/L
7.	Nitrates	1,3 Mg/L	40 Mg/L
8.	Nitrites	0,35 G/L	0,08 Mg/L
9.	Ammonia	0,05 G/L	0,39 Mg/L
10.	Common nitrogen	1,6 Mg/L	50 Mg/L
11.	Common phosphorus	0,2 Mg/L	0,0001 Mg/L
12.	Biochemical demand for oxygen	5,7 Mg/L	it must not be 3 Mg/L
13.	Chemical demand for oxygen	15 Mg/L	15 Mg/L –30 Mg/L
14.	Oil pipelines	0,7 Mg/L	0,05 Mg/L

Table 2. Analysis of ballast waters taken from the tanker "Seaspress" in the Kulevi port

N	Showings	Sample	Norm
1.	Oxygen dissolved in water	8,4 Mg/L	6,0 Mg/L
2.	pH	7,9	6,5–8,5
3.	Salinity	16,7 Mg/L	19,0–22,0‰
4.	Weighted particles	2,0 Mg/L	30 Mg/L
5.	copper	0,7 Mg/L	0,001 Mg/L
6.	Iron	0,09 Mg/L	0,005 Mg/L
7.	Nitrates	1,35 Mg/L	40 Mg/L
8.	Nitrites	0,4 Mg/L	0,08 Mg/L
9.	Ammonia	0,07 Mg/L	0,39 Mg/L
10.	Common nitrogen	1,9 Mg/L	50 Mg/L
11.	Common phosphorus	0,21 Mg/L	0,0001 Mg/L
12.	Biochemical demand for oxygen	5,9 Mg/L	it must not be 3 Mg/L
13.	Chemical demand for oxygen	15,8 Mg/L	15 Mg/L –30 Mg/L
14.	Oil pipelines	0,5 Mg/L	0,05 Mg/L

Table 3. Poti Port - N 5 Watershed Water Supply Sample 2017.04**Table 4.** Poti Port- anker "Cassiopea Star"– Agricultural fecal water sample taken from the clearing plant from the pipe 2017. 02

water t°	12° C
Colour	Colorless
smell	1 Bal
Sediment	No
Transparency	Transparent
Weighted particles	4,0 Mg/L
Dry balance	–
Chlorides	–
PH	8,5
Residual chlorine	–
Ammonium	1,67 Mg/L
Nitrates	–
Oxygen soluble in water	5,9 Mg/L
water t°	10° C
Colour	yellow
smell	5 Ball
Sediment	Yes
Transparency	Turbid
Weighted particles	58 Mg/L
Dry balance	–
Chlorides	–
PH	5,3
Residual chlorine	13,0 Mg/L
Ammonium	–
Nitrates	–
Oxygen soluble in water	3,8 Mg/L

"Results of laboratory chemical research on Poti and Kulevi water pollution are given in the following tables (1, 2, 3, 4). Pollution indicators are comparable to international standard standards as well as surface water pollution sanitary norms, with all metallic content not exceeding the permissible concentration concentrations (black, cold, water, cadmium, copper, bullet).

Secondly, the research of the "Poti (landing-stage) Water and Air Relative Temperature Forecast" was carried out during the 4 seasons of 2017. The average value of relative temperature is equal to:

$$1) \quad t_1/t_2 = \frac{\sum_{i=1}^n (t_1/t_2)_i}{N} = \frac{\sum_{i=1}^{50} 21.54}{50} = 0,87$$

The average value of relative temperatures during the 4 seasons of 2017 for the Kulev berth is equal to:

$$2) \quad t_1/t_2 = \frac{\sum_{i=1}^n (t_1/t_2)_i}{N} = 0,87$$

"Water Potential (TDS) Forecast" - One of the most important features of the Black Sea ecological parameters is the determination of salinity of sea water, which basically determines the state of flora and fauna. The statistical order obtained as a result of the survey results in 50

points - the law of distribution of salinity change in the Black Sea by using reliability and risk theory. "The mean value of salinity of Poti berth (TDS) is equal to:

$$1) (TDS) = \frac{\sum_{i=1}^n (TDS)_i}{N} = \frac{\sum_{i=1}^{50} (689.13)_i}{50} = 15.60$$

The average value of salinity (TDS) during the 4 seasons of 2017 at Kulev berth is equal to:

$$2) (TDS) = \frac{\sum_{i=1}^n (TDS)_i}{N} = 15.12$$

"The prediction of sea water acidity (pH) of Poti (sea level)" - The surveys carried out in the Black Sea waters of Georgia, whose statistical rank has also been 50 points, allows for a sea water acidity (pH), the mean value of which is:

$$1) \quad pH = \frac{\sum_{i=1}^n (pH)_i}{N} = \frac{\sum_{i=1}^{50} 8.37}{50} = 8,37$$

During the 4 seasons of 2017 for the Kulevi berth. Acidity (pH), the average value of which is equal to:

$$2) \quad pH = \frac{\sum_{i=1}^n (pH)_i}{N} = 8,34$$

3. Conclusion

As a result of the works carried out by the reliability and risk theory, the average value of salts (TDS) for the Kulevi berth is equal to: 15,12 mg / dm³ and acidity - 8,34; For Poti Port, the average value of salinity is 15,60 mg / dm³ and acidity - 8,37.

In the theoretical and laboratory studies we have found that the risks of contamination of ports and ballast waters are expected to increase.

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ELECTRONIC THROTTLE DEVELOPMENT FOR EXPERIMENTAL HYBRID-ELECTRIC VEHICLE

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Abstract: This paper presents a design proposal for an electronic throttle control system intended for the experimental light hybrid-electric vehicle. This vehicle was made in the scope of ongoing student project of developing and creating a light hybrid-electric vehicle as a platform for educational and research work. In the present case, ATV/quad-vehicle engine is used, where the throttle command of IC engine was originally realized using mechanical linkages and cable. In order to fully exploit hybrid drive potentials, control of both IC engine and electric hub motors had to be exerted by using single accelerator pedal. For this purpose, the original IC engine control system had to be replaced by an electric motor actuator that uses control signal from accelerator pedal used for electric motors control. The prototype of mechanism that converts rotation of electric motor actuator output shaft into linear displacement of the needle valve was also designed and produced applying 3D printing technique.

Keywords: ELECTRONIC THROTTLE CONTROL, ELECTRIC DRIVE, HYBRID DRIVE, PROJECT-BASED LEARNING, STUDENT PROJECT

1. Introduction

The aim of Electronic Throttle Control (ETC), alongside improving vehicle's performance, is reducing emissions and improving fuel economy. Unlike traditional throttle system that uses mechanical linkage between the acceleration pedal and the throttle, ETC uses several sensors and actuators for regulating airflow in the intake manifold [2]. This project implies a mechatronic approach as it was designed as a combination of different engineering fields (e.g. mechanics, electronics, and programming).

A vehicle that was developed through student project, is configured as a parallel hybrid with IC engine power on the rear axle and two electric hub-motors on the front axle. Such drivetrain configuration enables different operating modes. For example, the vehicle can be driven using either the IC engine or the electric drive independent of each other. Further, these two power sources can work simultaneously, whereby two different approaches can be distinguished. One of them is the economic mode, where IC engine operates around the most efficient energy conversion point, while electric motors provide additional torque required for a smooth and stable drive or moderate acceleration required by the driver. The other one is achieving maximum torque, using full throttle control for the IC engine and torque boost provided by the electric drive. Finally, regenerative braking can be used to further improve the overall fuel economy. Carburetor control is based on the needle valve, so that special features of such a system had to be taken into account in the scope of the designing process. For this purpose, the original IC engine control system had to be replaced by an electric motor actuator that uses control signal from accelerator pedal used for electric motors control.

Design of such conversion is the main goal of this work. Designing process for the prototype of the mechanism that converts the rotation of electric motor actuator output shaft into linear displacement of the needle valve will be described. 3D printing technique has been utilized in realization of the project. The new control system also uses the controller with the appropriate software which converts the control signal to the actuator displacement.

2. Results and discussion

There are three types of hybrid drive structures

- Serial
- Parallel
- Split power hybrid drive (has a combination of both properties serial and parallel hybrid drives) [3]

The vehicle described in this paper is constructed as a parallel hybrid drive gaining power from two different power sources. Two in-wheels electric motors are controlling the front axle and the IC engine is controlling the rear axle. By using parallel drive configurations those two power sources can work either simultaneously or independently. Both current vehicle and powertrain components are shown in Figures 1, 2 and 3 [1].

Due to having two power sources, this vehicle contains two separate acceleration pedals. This configuration is to be improved by implementing ETC system that would result with usage of conventional, driver-friendly single pedal system and so-called throttle-by-wire control. ETC system's task is to provide an electronic connection from the acceleration pedal to a microcontroller up to the electric motor actuator, which serves to power the excenter mechanism that is directly connected to a carburetor.



Fig.1 Current appearance of the vehicle [1]



Fig. 2 Front axle with in-wheel electric motors and batteries (a) and Rear axle with the conventional passenger-car final drive, driven by IC engine (b) [1]

There are various carburetor types, most common ones are with the throttle valve, and however, carburetor described in this paper is one with the needle valve, which makes it rare in the terms of automatization. The first approach was to model simplified models of acceleration pedal and the carburetor which was done in Catia V5 Student version (Fig. 3). The idea was to build a gear rack mechanism that converts rotary to linear motion, but it was eliminated due to printing difficulties. A mechanism that was easiest to print, yet equally efficient, was an excenter mechanism (Fig. 4). This mechanism only needs to overcome the spring force because needle valve configuration is simpler than the throttle valve configuration.

Electric motor actuator, suitable for this type of application was a DC servo motor (model *micro servo sq90* was used) because of it's a quick response to fast changing input signals. There was no need for an additional sensor, like the linear potentiometer, because chosen servo motor already has a potentiometer in its housing, which acts as a sensor. Servo motor is controlled via PWM signal through an Arduino microcontroller and signal gained from the servo's potentiometer is used as a feedback meaning this prototype is controlled in a closed loop. Additionally, input signal was received from the potentiometer (used as a substitution for the real acceleration pedal) which determined acceleration pedal's position by giving the output voltage depending on a pedal's angle i.e. force made while stepping on a pedal.

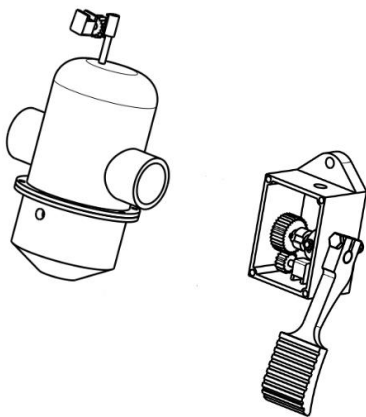


Fig.3 Simplified models including needle valve carburetor and acceleration pedal

Ultimaker 2 extended 3D printer was used for printing the prototype (Fig. 4) using ABS (Acrylonitrile Butadiene Styrene) filament and technology named fused filament fabrication (FFF). Firstly the filament is extruded, heated to a working temperature and then forced through the heated nozzle, which diameter is smaller than 1 mm. While nozzle stays fixed, printer's platform beneath the nozzle is moving in X/Y/Z directions, allowing fresh layers to fuse on top of the previous, cooled ones. All together, approximate time for printing the prototype was around four hours.

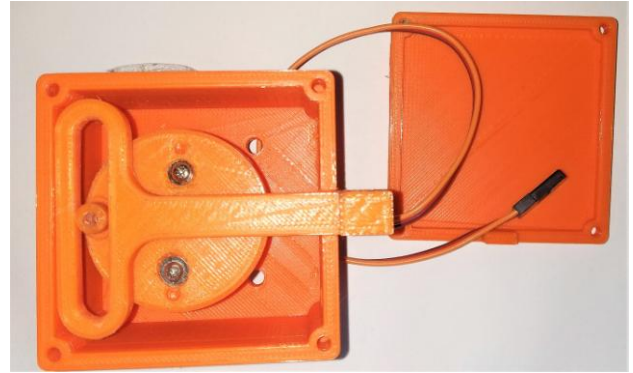


Fig. 4 3D printed excenter mechanism

3. Conclusion

Comparison of the working principles between the throttle and a needle valve results with the conclusion that the needle valve mechanism is much simpler meaning it requires simpler control. The prototype used in this paper was controlled without any PID controller unlike the one in [2], but adding the PID controller could be accomplished in future development. Further improvements that could be realised are adding more sensors for getting more reliable output signals and designing a control logic in Matlab/Simulink by using model-based technology. Additional tests could be done, based on considering what external impacts could cause unwanted mechanism behavior such as excessive vibrations, environmental conditions, wear of materials, etc.

4. Acknowledgments

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IDENTIFICATION OF THE MINOR CHEMICAL ELEMENTS IN THE EXHAUST EMISSIONS FROM DIESEL ENGINE VEHICLES

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Abstract: In this research we investigate the minor chemical elements contain in the particulate matter (PM) exhaust emissions, generated from in - use light duty Diesel combustion engine vehicles. For this purpose we apply high resolution optical emission spectroscopy technique, for precise spectrochemical analysis of Diesel particulate matter (DPM). By means of Laser Induced Breakdown Spectroscopy analytical method we analyse PM from different on road Diesel engine vehicles. DPM were obtained from miscellaneous in-use Diesel engine passenger vehicles of diverse types and models from major brand car producers in Europe.

Keywords: BLACK CARBON, DIESEL ENGINE, DIESEL EMISSIONS, PARTICULATE MATTER, SOOT, DIESEL VEHICLES

1. Introduction

The existing emission standards like Euro, Tier, or LEV, for light-duty Diesel engine vehicles specify the maximum allowable emissions of hydrocarbons, carbon monoxide, nitrogen oxides and particulate matter (PM). PM is measured as the total number of all generated particles from Diesel exhaust. On another hand, there are no specific emission standards for additional compounds or chemical elements contained in the exhaust emissions i.e. in exhaust vapour, in Diesel particulate matter (DPM), in particulate matter (PM), in black carbon / carbon black (BC/CB), or in the soot formed by the Diesel combustion engine. Even though, the chemical elements additional to carbonous particles, present a large fraction of the total DPM or soot emission contents.

Generally, exhaust emissions from Diesel engine can form a very complex mixture of gases, vapour and particles consisting of countless elements and compounds. Gaseous compounds of Diesel emission include carbon dioxide, oxygen, nitrogen, water vapour, carbon monoxide, nitrogen compounds, sulphur compounds, and numerous low molecular weight compounds [1]. The vapour phase contains larger molecular weight compounds, located in unburned tailpipe emissions. The Diesel exhaust particles are agglomerates of many primary spherical particles that differ in size [2], composition [3] and solubility [4]. The particles in Diesel exhaust emission consist of particulate matter - Diesel particulate matter. This is further classified, depending on the size of particles to: particulates of an aerodynamic diameter of less than 10 μm , fine particles of diameters below 2,5 μm , ultra fine particles - below 0,1 μm and nanoparticles - characterised by diameters less than 50 nm. DPM is composed of elemental carbon in core and adsorbed compound. The elemental carbon core has a high specific surface area and serves as a nucleus for condensation of compounds with good adsorption properties mainly from the unburned or incompletely burned Diesel, particles or from crankcase oil volatilized metallic nano-particles from the cylinder walls.

The aim of this research is to investigate the minor chemical elements contained in the particulate matter exhaust emissions, generated from standard in - use light duty Diesel combustion engine vehicles. For this purpose we apply high resolution optical emission spectroscopy technique for precise spectrochemical analysis of DPM. By means of Laser Induced Breakdown Spectroscopy analytical method we analyse PM from different on road Diesel engine vehicles. DPM were obtained from miscellaneous in-use Diesel engine passenger vehicles of diverse types and models from major brand car producers in Europe.

2. Methodology

Laser induced breakdown spectroscopy (LIBS) [5, 6, 7] is an optical measurement technique [8] for rapid qualitative [9] and

sensitive quantitative [10] compositional analysis of various forms of materials like solids [11], liquids [12], gases [13], powders [14] or nanoparticles [15].

In Laser Induced Breakdown Spectroscopy a high power laser radiation, with nanosecond or shorter pulse duration, is interacting with the investigating material [16]. This short light – matter interaction generates a plasma, of which the optical emission spectrum is collected by the optical spectrometer and then further processed by computer. From LIBS spectra, the elemental chemical composition of the examined sample can be obtained. The qualitative spectral information can be further calibrated, to obtain quantitative results. The LIBS technique provides very sensitive and rapid analytical measurements, without sample pre-treatment, in the range of ppm levels [17], almost instantaneously. This advantage pushes the LIBS technique forward in many new research areas and makes it also attractive for industrial applications [18].

The LIBS technique can almost instantly measure the minor compounds of DPM and provide the qualitative results about the chemical composition. The fingerprints of minor chemical elements in PM exhaust emissions are related to different processes. These are: fuel quality, fuel composition, additives, performance of combustion, catalytic reaction, particulate filtering technique, or wearing of the Diesel engine.

3. Experimental setup

3.1 Experimental LIBS setup

The experimental setup for LIBS measurement, consists of high intensity pulsed laser system, experimental chamber, collection optics and with high precision optical spectrometer. Laser beam is guided via optical mirrors into the focusing lens. Plasma is generated by focusing of laser radiation into the material. Schema of LIBS experimental set-up is shown in Fig. 1.

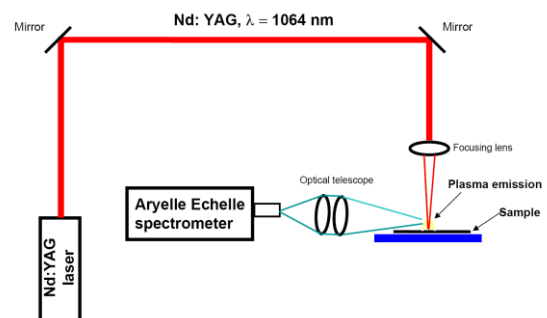


Fig. 1 Layout of LIBS experimental setup..

For laser induced plasma we have used solid state Nd:YAG laser from Quantel. The laser has 8.5 ns pulse duration, and fundamental laser wavelength operating at 1064 nm in invisible

infrared spectrum. For the measurements we have used the laser energy of 300mJ per single pulse. Due to the large variations of different DPM samples, we apply higher laser energy, to enhance the plasma emission and ensure the gain in overall optical signal for all spectra lines and samples. The laser radiation has been focused with 10 cm focusing lens into the plane solid target surface to create plasma. Optical emission from plasma has been collected perpendicularly via optical telescope into the high resolution Echelle spectrograph model Aryelle Butterfly from LTB Berlin equipped with ICCD detector. Spectrometer consists of two separate spectrographs, one part for UV range from 190 nm to 440 nm and the second part for VIS optical spectrum in range 440 nm to 800 nm. Spectral resolution capability is from 3 - 7 pm for VUV part and 4 - 8 pm for VIS part, thus providing spectral information of a broad spectral range with high resolution and variability. The delay time 1µs and gate width 2 µs after the trigger signal has been used. The LIBS emission has been recorded in open air atmosphere under a atmospheric pressure at room temperature.

3.2 Particulate Matter collection and sample preparation

Sixty-seven different samples from in-use Diesel engine passenger vehicles of major brand car producers in Europe have been analysed by LIBS. Vehicles selected for the DPM sample collection were from our daily life environment, as anyone is using to drive to work, etc, no special driving test cycles vehicles or engines were used. Diesel Particulate Matter has been collected and extracted from the tail pipe at the end of the exhaust manifold, after the Diesel Particulate Filter (DPF), if it was applied. Selections of the vehicles were performed randomly and no company was given preference. The collected DPM from Diesel engine vehicles exhaust has been mechanically pressed into the small pellets with 6mm diameter and with flat disc shape.

4. Results and discussion

4.1 Identification of the major elements in the DPM

Obtained signal from Laser Induced Breakdown Spectroscopy measurements of Diesel Particulate Matter from three selected samples, are shown in the Fig. 2. The strong optical emission is characterise from Carbon, Iron, Magnesium, Aluminium, Chromium, Zinc, Sodium and Calcium. These elements were previously identified in PM as major components of Diesel Particulate Matter [19].

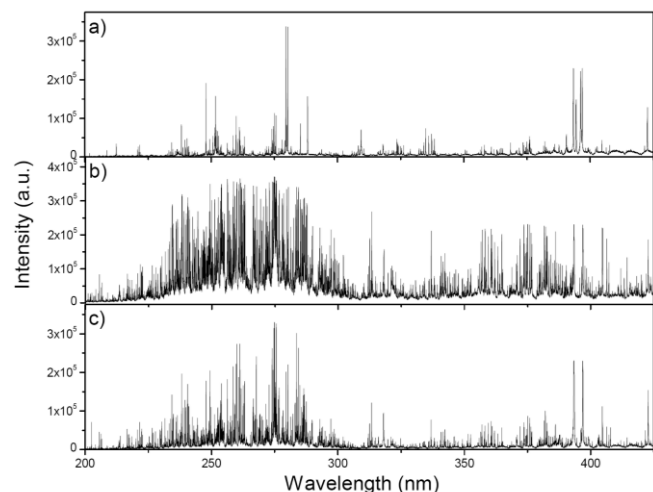


Fig. 2 Optical emission LIBS spectra from three different particulate matter samples. High intensity spectral lines are from Carbon, Iron, Magnesium, Aluminium, Chromium, Zinc, Sodium and Calcium.

LIBS spectra generated from particulate matter collected from in-used Diesel engine light-duty vehicles exhibits a characteristic

spikes - optical emissions lines with distinct of atomic, ionic and molecular origin included in the signal.

4.2 Identification of the minor elements in the DPM

To identify the minor elements of DPM the state-of-the-art laboratory Laser induced breakdown spectroscopy setup has been used to obtain high resolution optical emission spectra image. The qualitative LIBS results of these measurements are shown in Fig. 3(a-f). Obtained signal from minor chemical elements are characterised by strong optical emissions from: a) Silicon, b) Nickel, c) Titan, d) Potassium, e) Strontium and f) Molybdenum.

Minor elements of DPM matrices:

Silicon spectral line: atomic emission from Si I @ 288.15nm is shown in the Fig. 3a. In this figure the raw spectral signal from LIBS measurements of sixty-seven different samples of Diesel particulate matter are shown. From this spectroscopical results one can observe that the Silicon signal, mainly peak shape, peak intensity and peak width at FWHM varies for each DPM sample. The strength of the LIBS signal of particular atomic or ionic line is basically proportional to the concentration of the analyte in studied sample. Therefore for detail comparison we numerically calculated the integral values of each signal peak to obtain qualitative information about chemical composition of Diesel particulate matter. The results from these calculations are shown in Fig. 4a. Here one can easily compare the variations of Silicon signal / concentrations (a.u.) within diverse DPM matrices. However for detail quantitative analytical characterisation of Si in DPM, the calibration of LIBS signal would be desirable. To compare; very high content of Si is in the sample # 51, 31, 25, 55. From LIBS analytical measurements and numerical calculations we can conclude that Silicon is minor element and it has been measured in 63 from 67 different DPM samples.

Nickel spectral line: in Fig. 3b the comparisons of ionic emission from Nickel, spectra line Ni II at 221.64nm is shown. One can see, that this signal is quite strong. The calculation of signal integral values is in Fig. 4(b). Samples with high content of Nickel are #12, 4, 34, 5, 20. Nickel in DPM is present as minor element in the 43 samples.

Titan spectral line: is compared in Figure 3c, where the ionic spectra lines Ti II at 334.94nm is shown. From the numerical calculation in Fig. 4c one can see, that optical emission from this element is present in 32 DPM matrices. High content of Titan is present in sample #51, 55 and 59.

Potassium spectral line: is shown in Fig. 3d, as atomic line K I at 766.48nm in infrared spectral range. High content has been measured in sample #51, 4, 26, 28, 25 and 8. The comparison of integral spectral peak calculated values are shown in Fig. 4d. Potassium is present in 50 different samples.

Strontium spectral line: the raw peak signal from sixty-seven different DPM samples is shown in Fig. 3e. The Sr ionic line Sr II at 407.77nm, is present in visible spectral range. From numerical calculation in Fig. 4e the Strontium as minor element has been measured in 35 different DPM samples. Strong signal from Sr is in sample #4 and 51.

Molybdenum spectral line: atomic emission Mo I @ 313.25nm is shown in Fig. 3f. From the figure, higher content of molybdenum is in two samples, #12 and 59. Molybdenum as minor element has been measured in 17 different DPM. The comparison of integral values are shown in Fig. 4f.

In Table 1 are summarised measured analytes, the spectral atomic or ionic lines used for analytical LIBS measurements and number of samples where the minor element has been successfully detected.

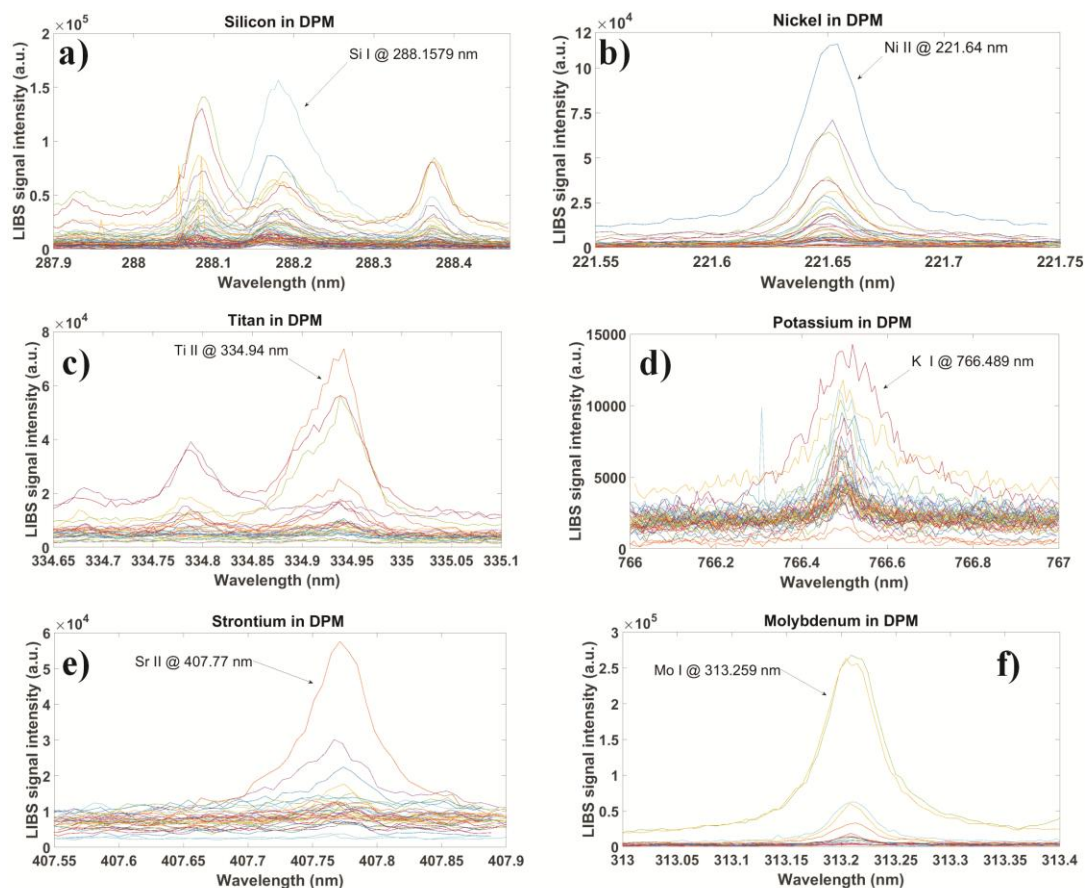


Fig. 3 Optical emissions spectrum from: a) Silicon, b) Nickel, c) Titan, d) Potassium, e) Strontium and f) Molybdenum signal, measured by high resolution LIBS technique from Diesel particulate matter collected from in-use passenger Diesel engine vehicles.

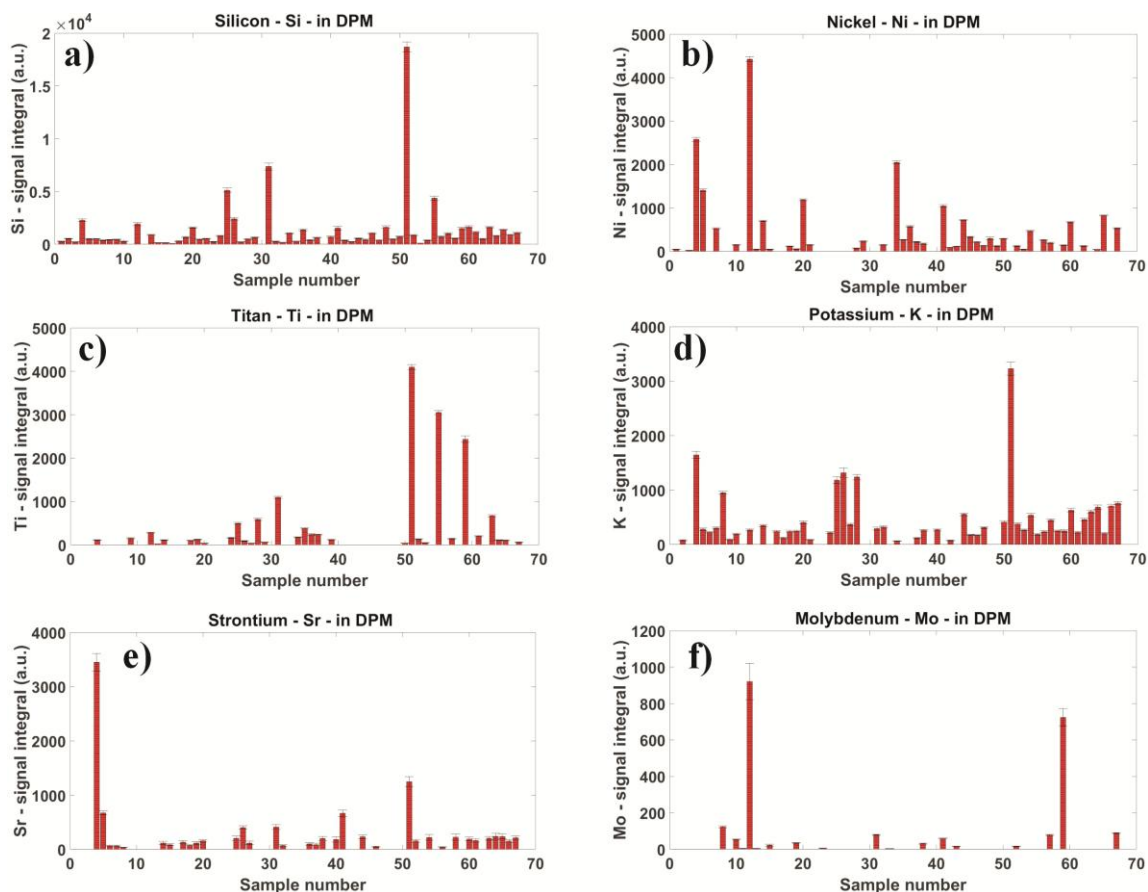


Fig. 4 Comparison of calculated integral values from optical emissions spectrum of a) Silicon, b) Nickel, c) Titan, d) Potassium, e) Strontium and f) Molybdenum minor chemical elements in Diesel Particulate Matter.

Table 1: Spectral lines used for analytical measurements and number of samples with detected element.

Analyte	Spectral line	Wavelength (nm)	Detected in / total number of samples
Si	Si I	288.15	63 / 67
Ni	Ni II	221.64	43 / 67
Ti	Ti II	334.94	32 / 67
K	K I	766.48	50 / 67
Sr	Sr II	407.77	35 / 67
Mo	Mo I	313.25	17 / 67

5. Conclusions

In this paper, we have investigated the minor chemical elements present in Diesel Particulate Matter. The DPM have been collected from sixty - seven different in-use Diesel engine passenger vehicles. Selections of Diesel passenger vehicles have been performed randomly, from daily life environment and from major brand car producers in Europe. Particulate matter have been analysed spectrochemically by means of a high resolution laser induced breakdown spectroscopy (LIBS) technique. The qualitative analytical results have shown the presence of minor chemical elements: Silicon, Nickel, Titan, Potassium, Strontium and Molybdenum in Diesel particulate matter. These elements were measured by LIBS as strong spectral lines of atomic and ionic emission in laser induced plasma. The spectral LIBS signal from each minor element was further numerically processed. The integral values of individual signal lines have been calculated to obtain qualitative comparison of individual minor elements in different Diesel particulate matter matrices. From analytical measurements and numerical calculations we can conclude that Silicon as minor element has been detected in 63 from 67 DPM samples. Nickel and potassium have been detected in 43 and 50 samples, respectively. Titan in 32 and Strontium in 35 samples of DPM. The Molybdenum element have been detected in 17 DPM samples from different in-use Diesel engine passenger vehicles.

Measured minor elements Si, Ni, Ti, K, Sr, Mo together with major elements C, Fe, Mg, Al, Cr, Zn, Na and Ca are forming important part of Diesel particulate matter composition. All these elements are altogether contributing to overall exhaust emissions from Diesel engine passenger vehicles.

We can conclude that the LIBS technique can almost instantly measure the major and minor compounds of DPM to provide qualitative information about the chemical composition. The presence of these chemical elements in PM exhaust emissions are related to different processes in Diesel combustion engine.

However in the future, a detail quantitative analytical characterisation of minor elements, together with calibration procedure would be necessary to obtain. This would help to understand the minor element concentrations in Diesel particulate matter.

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1D SIMULATION-BASED DEVELOPMENT OF A SAFETY CONCEPT FOR THE INVESTIGATION OF A HIGH-PRESSURE GAS-DIESEL INJECTOR ON A SINGLE-CYLINDER RESEARCH ENGINE

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Abstract: 1D simulation has significantly supported the process of developing a diesel ignited high-pressure gas direct injection combustion concept, thus facilitating promising investigations at the SCE. It has been applied to a variety of tasks such as designing the media supply system, pre-optimizing engine operating parameters and developing the safety concept discussed in this paper. Application depends on two simulation models in particular: one validated MCE model and one SCE model enhanced in the course of the concept design phase. Since the MCE model can reliably reproduce the behavior of a full engine with single-stage turbocharging, it played a critical role in determining the boundary conditions for both the 3D-CFD simulation and the simulations with the SCE model. The SCE model, on the other hand, includes all components relevant for the test bed and thus permits both a reliable design of the gas path and the development of a safety concept, which is of remarkable importance for high-pressure gas applications. With regard to the safety concept, this paper presents and discusses the difficulties in detecting injector malfunction and different detection strategies.

Keywords: DIESEL AND GAS FUELED ENGINES, 1D SIMULATION

1. Introduction

The potential for savings in greenhouse gas (GHG) by substituting gases with high methane content (e.g., natural gas) for conventional liquid fossil fuels is considerable due to the comparatively low carbon dioxide emissions, cf. [1, 2]. Applications such as monovalent gas engines and diesel-gas engines that operate on the Otto cycle already exploit this GHG saving potential and are well known for their low emission of both particulates and NO_x as well as for high engine efficiencies, cf. [3, 4].

However, the feeding of a premixed gas-air mixture may result in knocking combustion when gases with low methane numbers are used as well as methane slip. Gas-diesel engines based on the diesel cycle directly inject the gaseous fuel into the combustion chamber during the high-pressure phase of the engine cycle. Ignition is triggered by the injection of a small amount of diesel pilot fuel. The resulting mixture-controlled combustion is not prone to knocking and as a consequence, low-quality gases can be used at high compression ratios and therefore high thermal efficiency. Furthermore, these engines have the potential to avoid engine-out methane emissions nearly entirely. Fully flexible gas-diesel engines [4] can be operated either in dual fuel (DF) mode with gaseous fuel as the main energy source or in diesel mode. This redundancy is important in marine applications in particular where fail-safe operation is critical. Application of these engines in liquefied natural gas (LNG) tankers is economically advantageous as the boil-off gas from the LNG storage system is effectively transformed into propulsion energy, thereby increasing overall efficiency, cf. [5, 6].

The development of a new dual fuel gas-diesel engine concept requires the definition and pre-optimization of many parameters in advance. Additionally, the system complexity resulting from having to provide two fuels simultaneously is higher than with monovalent engine concepts. Boundary conditions, knowledge of the thermodynamic states in the combustion chamber during the engine cycle as well as concept specific information on ignition and combustion are all required in the development process. Therefore, the 1D simulation that is part of **LDM** (**LEC Development Methodology**) [10] is a good tool that meets the demands of this type of investigation. This paper explains how 1D simulation is applied to a variety of different tasks in the development of a DF

gas-diesel engine concept, focusing on a safety strategy for the single-cylinder engine (SCE) test bed.

2. Fuel injection system for gas-diesel engines

One challenge of injecting fuel into gas-diesel engines is that both diesel and gas must be provided at high pressure (HP) levels when they are injected into the combustion chamber at the end of the compression phase. For HP diesel generation, pressure control and media guidance, standard systems can be used. In contrast, HP gas applications for high-speed large engines are less common and the subject of current development activities, cf. [9]. Furthermore, it is particularly challenging to integrate more than one injection valve into the cylinder head. With respect to slow-speed and medium-speed large engines, systems with two or even more fuel injectors are feasible, cf. [5, 7]. In high-speed large engines that feature high power density, however, how the components are packaged within the cylinder head is critical because available space is limited.

From investigations of diesel-gas engines with premixed combustion, it is well-known that an off-center positioning of the pilot diesel injector in the cylinder head has disadvantages over the pilot diesel injector being situated in the center, cf. [4]. The off-center ignition of the lean gas-air mixture results in asymmetrical flame propagation, which in turn affects efficiency and combustion stability. Similar disadvantages can also be expected with the gas-diesel concept if the injectors are not arranged centrally.

Therefore, advanced injection systems use instead of a multi-injector arrangement one combined gas-diesel injector installed in the center of the cylinder head in which the diesel nozzle is surrounded by the gas nozzle holes, cf. [8]. To obtain the best engine performance possible while complying with stringent emission legislation, the injector has to provide great flexibility in terms of injection timing, multiple injection and injection pressure with both diesel and gas injection. In order to ensure that the injector is always supplied with the required gas pressure and sufficient gas mass flow during the injection process as well, the gas path must be designed accordingly.

3. Advanced high-pressure gas-diesel injector

A recently developed advanced combined HP gas-diesel injector for large high-speed gas-diesel engines meets the demanding requirements described in the previous section. By applying common rail technology, the diesel fuel and the gaseous fuel can be injected flexibly and independently of each other. The

gaseous fuel is injected through three groups of gas nozzle holes; each group has a separate gas needle (one, two or three holes per group). All three groups are positioned symmetrically around the diesel nozzle 120° from each other.

A prototype of a combined gas-diesel injector is available for a detailed investigation and evaluation of the injector concept. The maximum diesel rail pressure of this prototype is limited to 1600 bar in diesel operation mode. In dual fuel operation mode, the diesel rail pressure is limited to 1300 bar and the gas rail pressure is limited to 500 bar. Both gas injection and diesel injection are actuated by two independent valves that are electronically controlled by a modified engine control unit.

4. Media supply of the HP gas-diesel injector

Before the high-speed four-stroke single-cylinder research engine with the diesel-gas injector centrally mounted in the cylinder head is ready for tests, a media supply system has to be developed that is capable of achieving the required gas pressure and sufficient gas mass flow during the injection process in particular. The rough boundary conditions for the design of the media supply are largely specified by the engine application. The detailed engine specifications are given in Table 1.

Table 1: Technical specifications of the SCE

Rated speed	1500 rpm
Displacement	≈ 6 dm ³
Compression ratio	16:1
Number of inlet/exhaust valves	2/2
Valve timing	Miller intake valve timing
Swirl/tumble	≈ 0/0
Charge air	Electrically driven air compressor with up to 10 bar boost pressure
Gas fuel supply	High-pressure ionic compressor with up to 600 bar gas pressure
Diesel fuel supply	Common rail system with up to 2200 bar diesel fuel pressure

A well-known common rail technology was used for the diesel supply. In addition, the gas-diesel injector requires a high-pressure gas supply for operation in DF mode. In order to provide the required gas pressures and masses, a new high-pressure gas path in combination with an extended safety concept was developed and implemented at the LEC.

An ion compressor boosts the gas pressure from the low public gas grid level up to 600 bar. The gas pressure in the gas path between the buffer volume and injector is adjusted precisely with finely resolved control valves located downstream of the compressor for fully flexible engine operation. In combination with the latest crank-angle and time-based measurement technology, a special high-pressure NG Coriolis mass flow device monitors all relevant parameters.

Compared to diesel applications with sophisticated flow limitation valves, however, the aggregate state of HP gas poses an increased risk to the engine in the event of injector malfunctions. To identify potential issues that arise during injector malfunction and to develop risk minimization strategies, the gas path shown in Figure 1 was the subject of extensive 1D simulation during the predesign process. In the direction of gas flow, this path consists of a HP gas buffer volume with a pressure sensor, a safety valve (SV) and another pressure sensor directly upstream of the injector. All these components are highly important for the test bed safety concept and will be discussed in more detail below.

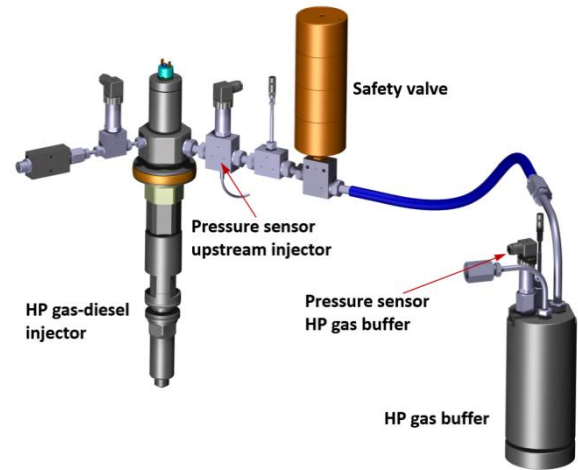


Fig. 1 Media supply of the injector: gas path

5. Application of 1D simulation to develop a safety concept on the test bed

5.1. Development of 1D simulation models to support the design of a hardware configuration on the test bed

Different 1D simulation models were applied to support the predesign of the gas-diesel combustion concept. Boundary conditions for 3D CFD simulations as well as required engine performance data were calculated with a 1D simulation model of a multicylinder gas-diesel engine (MCE) with one-stage turbocharging. To depict the combustion process with this 1D model, heat release rates (ROHR) were taken from the 3D CFD simulations. To account for the increasing cylinder charge caused by fuel injection during the high-pressure phase of the combustion process, the gas-diesel injector was implemented into the 1D model by including one gas and one diesel injector element in each cylinder.

Since another 1D model of the gas injector alone was required to predict the gas injection rate, a simplified submodel was developed which consists of a spring chamber, needles and a needle chamber, cf. Figure 2 (left). The submodel calibration was based on simulation results provided by the manufacturer of the injector. Figure 2 (right) shows how well the simplified model predicts the target injection at the same boundary conditions.

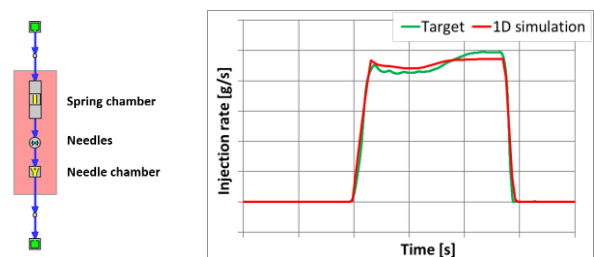


Fig. 2 Simplified 1D model of the gas injector

The calibrated 1D submodel of the gas injector was integrated into another model that focuses on the high-pressure gas path on the SCE test bed, cf. Figure 3. It includes all components of the gas supply path shown in Figure 1: HP gas buffer, safety valve, pressure sensors, HP gas injector, gas hose and pipes. The diesel injector is modeled separately. The conditions at intake and exhaust boundaries were taken from the 1D MCE simulation.

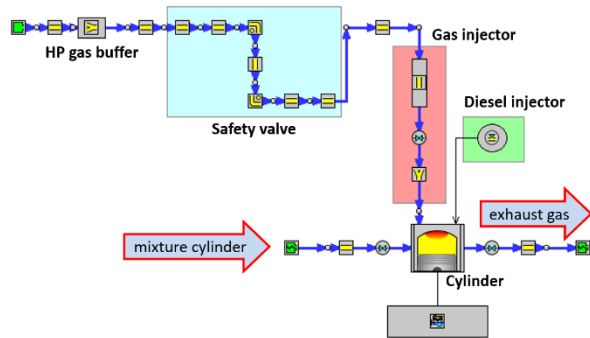


Fig. 3 1D model with HP gas path

5.2. Development of a safety concept of a high-pressure gas-diesel injector using 1D simulation

In the development of the reliable safety concept, the pressure conditions within the gas supply path during standard operation from engine start to stop were investigated with this 1D SCE model. All 1D investigations of the gas path used the measurement positions directly upstream of the injector and in the buffer volume. Building on these results, the same model was used to simulate the scenario of a stuck gas needle and its effect on the gas path respectively on the engine at different engine loads while taking the safety valve closing time into account. Finally, successful action strategies were derived. These strategies will be discussed in more detail below in the context of selected scenarios.

5.2.1. Malfunction due to the gas needle sticking during standard engine operation

Figure 4 shows the pressure curves directly upstream of the injector and in the buffer volume of two consecutive working cycles in the event of an injector malfunction during standard engine operation at part load (30%) and full load (100%). Irrespective of the load and position, almost identical pressure curves can be determined in the first working cycle (standard case) with a characteristic pressure fluctuation for the gas injection close to the specified pressure level. Compared to the second working cycle, which represents the scenario of injector malfunction due to the gas needle sticking, the gas pressure drops below the characteristic pressure fluctuation; this is seen most clearly with regard to the position upstream of the injector. In this case, a malfunction can be detected with a threshold value, i.e. if the pressure upstream of the injector falls below this threshold value, the closing process (≈ 0.1 s) of the safety valve is triggered immediately and the diesel injection is also switched off in parallel.

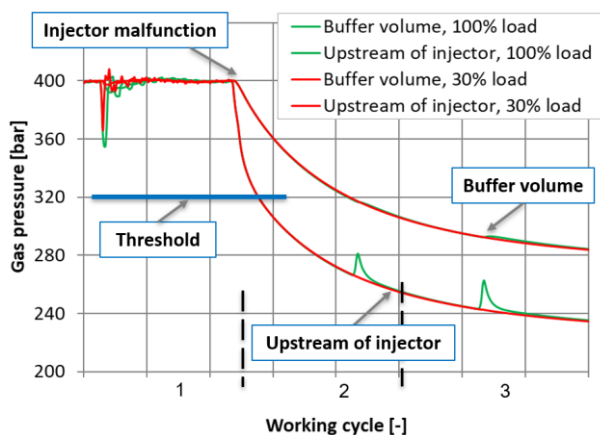


Fig. 4 1D simulation: detection of injector malfunction at different loads

Even if the safety valve closed immediately after the malfunction was detected, it would not be possible to hinder the gas remaining between the safety valve and the injector from expanding

into the combustion chamber. Figure 5 shows the impact of the gas needle sticking on three subsequent combustion cycles considering the valve closing time at 400 bar gas rail pressure. Combustion is represented by one ROHR, which is calculated using 3D CFD simulation for standard operation with the corresponding excess air ratio (EAR), cf. working cycles 1 and 2 in Figure 5. The same ROHR were used to simulate working cycles with injector malfunction, cf. working cycles 3, 4 and 5 in Figure 5. The results show that the gas remaining downstream of the safety valve influences at least three further cycles and produces very rich air-gas mixtures in the combustion chamber as well as an increased risk of engine damage.

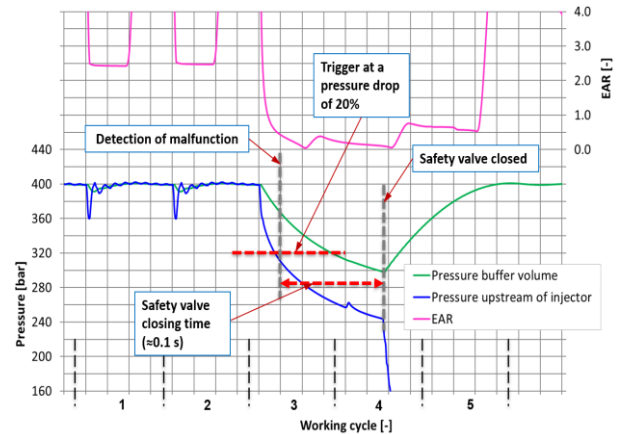


Fig. 5 Impact of injector malfunction on the cylinder charge

5.3. Malfunction due to the gas needle sticking at engine start

Even if an injector malfunction can be detected during standard engine operation, the same approach does not work during engine start. The following section reveals the difficulties in detection by comparing a case in which injector malfunction occurs with a case in which the injector work properly. In this case, the DF engine starting procedure corresponds the one shown in Figure 6. First, the engine is motored up to reference speed (not shown) and the pressure in the gas buffer is raised to the target value of 400 bar before pilot diesel injection occurs (1). In the next cycle, the safety valve is opened (2) and the gas stored in the buffer volume is then able to reach the injector. During this process, the pressure level upstream of the injector increases and finally reaches the same pressure rating as the buffer volume while the gas compressor supplies additional HP gas until the target value of 400 bar is restored throughout the entire gas path (3). Afterwards, the system is ready for the additional gas injection to start the DF mode (4).

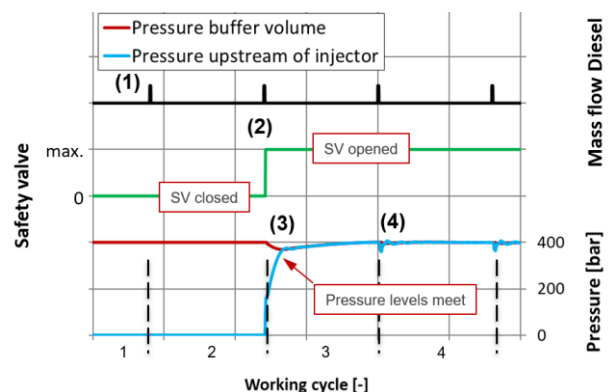


Fig. 6 Engine behavior without injector malfunction

Compared to the starting procedure discussed in Figure 6, the difference in the case of injector malfunction (cf. Figure 7) becomes clear after step (2).

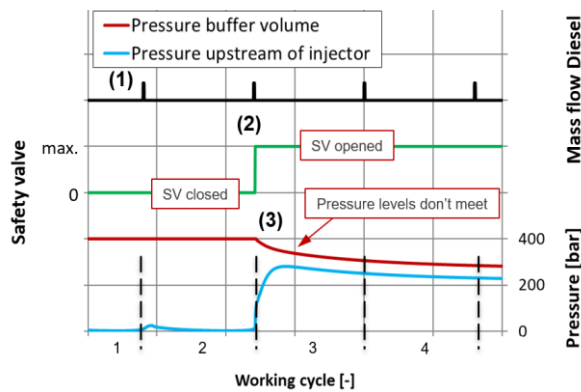


Fig. 7 Engine behavior with injector malfunction

Immediately after the safety valve is opened, the gas pressure directly upstream of the injector rises quickly but cannot meet the level of the buffer volume due to the stuck gas needle. Subsequently, the high pressure gradient between the HP gas path and comparatively low-pressure combustion chamber initiates an unlimited gas flow directly into the combustion chamber, which ultimately includes the previously mentioned dangers for the engine.

Since error detection in the gas path via a threshold value worked insufficiently in accordance to the simulation results, further simulations were carried out to identify additional helpful strategies. The indicated cylinder pressure signal was identified as a promising parameter for much faster detection of injector malfunction during both engine start and standard operation. In this gas-diesel concept, air alone is compressed between inlet valve closing (IVC) and start of injection (SOI) in standard operation independent of gas pressure or engine load. As a result, the pressure curve signal can be precalculated by a polytropic state change in this time window and used in a real-time comparison with the measured signal of the indicated pressure sensor, cf. Figure 8. If the gas needle stuck, additional gas would flow into the combustion chamber during this time window and the value of the measured indicated pressure would deviate from the predicted curve without delay. Thanks to this finely resolved monitoring, injector malfunction is detected very quickly and has been successfully used on the test bed in combination with error detection in the gas path via a threshold, which facilitates additional monitoring of malfunctions within the gas supply system.

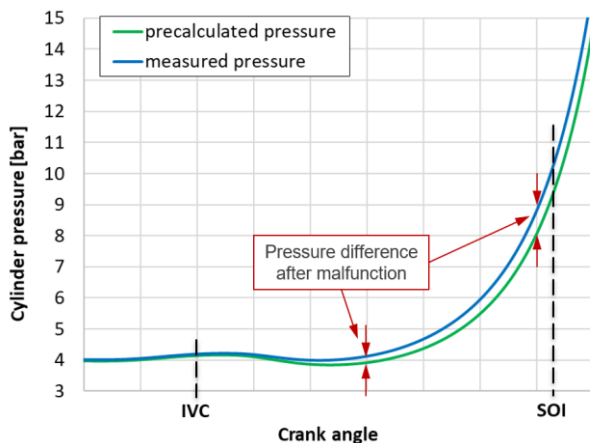


Fig. 8 Injector malfunction at one gas needle during standard engine operation

6. Summary

This paper presented the relevance of 1D simulations during the development process to investigate gas-diesel injectors on a high-speed large engine by taking different development issues into

account. 1D simulation models of different sizes and with different levels of detail were discussed in relation to each specific issue. Boundary conditions for 3D CFD simulations as well as additional engine performance data were calculated with the MCE model with one-stage turbocharging. In contrast to this extensive model, the high-pressure gas injector was depicted by a simplified model that simulates the required gas injection rates. As a consequence, it became possible to support the design of the gas-fuel supply system by optimizing the pipe and safety valve orifice diameters and reducing the pressure drop in the system.

With regard to safety issues, critical cases caused by injector malfunction were identified and simulated within various operating scenarios. Derived safety strategies for detecting an injector malfunction were discussed. The most promising strategy that was identified involves monitoring the cylinder pressure signal within a real-time comparison to a precalculated pressure curve in combination with error detection in the gas path via a threshold.

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SPECIATION OF C5-C11 HYDROCARBONS GENERATED BY THE HCCI GASOLINE EXHAUST GAS ENGINE

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Abstract: A qualitative and quantitative analysis of toxic but currently non-regulated hydrocarbon chemical species ranging from C5 - C11 was studied which is generated from a modern gasoline direct injection (GDI) engine by using gas chromatography-mass spectrometry (GC - MS). The GDI engine has been operated under different engine speeds and different engine modes (SI and HCCI modes). HCCI has the ability to operate on lean combustion which leads to the reduction in engine pumping losses, and fuel consumption. However, HCCI mode has a high level of unburnt HCs which leads to present heavier species such as Toluene, which is presented in higher concentrations under stoichiometric HCCI engine operation mode, while species such as benzene, are mainly found in the engine exhaust during SI engine operation. Engine speeds have high impact on engine tail pipe emissions for both engine modes. Increasing engine speed leads to higher concentration in Benzene species while toluene was decreased and presented in higher concentration at low engine speed for both engine modes.

KEYWORDS: HCCI, SI HYDROCARBON SPECIATION GDI

1. Introduction

In terms of emissions, hydrocarbon speciation is a powerful tool to understand the complex reactions happening inside the cylinder during the combustion process and to observe the effects of varying the fuel composition, fuel additives, and emission control system. Using speciation data enables researchers and scientists to evaluate the relative reactivity of the exhaust and evaporative emissions. Different hydrocarbons in urban air form from differing levels of ozone (smog) which depend on the reactivity of these chemical compounds. To evaluate hydrocarbon impact on ozone formation, HC speciation is required which will also help to determine the presence of toxic emissions from the exhaust tailpipe. Using speciation data has helped researchers to make a number of non-proprietary observations about the relationships between fuel property modifications and automotive emissions [1-2]

Clarifying the hydrocarbon components in conventional gasoline fuel is considered to be the key step in speciation of HCs in the engine exhaust. By using the retention times of some known compounds chromatograms and the NIST library together, the peaks in gasoline chromatograms could be identified. The hydrocarbons in gasoline consist primarily of light aliphatic hydrocarbons (butane, pentane, methyl-pentane, hexane, methyl-hexane, heptane and octane) and aromatic compounds (toluene, xylenes and trimethyl-benzenes), with smaller amounts of olefin hydrocarbons (pentene, hexenes, heptenes, octenes and nonenes). The content of toluene in this fuel sample is 13% by volume, and iso-octane is 11% by volume.

2. Experimental Work

The hydrocarbon speciation of C5-C11 coming out of the V6 HCCI engine (figure 1) was analysed and carried out using an on-line GC-MS. A Fisons 8000 series GC equipped with direct injector was connected to a Fisons MD 800 mass spectrometer, used as a detector. The gas samples were introduced via a heated line into a six-port Valco valve fitted with a 0.1 ml sample loop.

The fuel used for combustion investigation was analyzed by using another J & W scientific DB-1 column. This column gave details on the components (C5 to C11); presented in 95 RON unleaded commercial gasoline.



Figure 1: Schematic diagram of a V6 engine system

3. Results and Discussion

In general terms, the engine output emission concentration for all the studied chemical species was higher for HCCI combustion with the exception of benzene, which was presented more in SI mode. The higher unburned hydrocarbon emissions under HCCI combustion are due to the lower in-cylinder temperature and available energy to drive the complete oxidation reactions of the hydrocarbons part of the fuel and to also reduce hydrocarbon oxidation post combustion. On the other hand, the lower concentration of the rest of species under HCCI conditions can be attributed to i) the conversion of iso-octane to methane ii) a higher formation rate of toluene, p-xylene, naphthalene, methyl-naphthalene or any other compounds derived from benzene due to the higher presence of hydrocarbon to react with, and iii) the breakdown of the already formed toluene and p-xylene during SI combustion process producing benzene and ethylbenzene [3-7]. In SI mode as post-flame oxidation increases, the fraction of fuel paraffins to total hydrocarbons (THC) decreases because fuel paraffins are oxidized into smaller HCs (e.g. total olefins and methane). Benzene enrichment from aromatic fuels is of Benzene results from the incomplete combustion of toluene and other alkyl-benzenes.

The formation of benzene during combustion of the used fuel in this study which contains < 1.0 % explains the observed enrichment in the exhaust relative to other aromatic fuel components available in this commercial gasoline fuel. [8-10] Emission of benzene, increased by increasing the engine speed at SI mode on the other hand increasing speed at HCCI mode resulted in higher toluene species compared to SI mode. Figure 2 this constitutes an appreciable fraction of the total emission. The HCCI mode follows the same trend, but since the combustion temperature of HCCI mode is always lower

than SI mode under the same engine conditions, the oxidation of fuel paraffins is less. As a result the amount of total olefins, methane and benzene are lower than in SI mode. For toluene as well as for the other aromatics (e.g. xylenes) except benzene, there is a decrease in the percentage concentrations in the exhaust due to the increasing engine speed for both modes. The level of the toluene compound in the emission in both modes was the highest figure 3. In SI mode the amount of toluene is always lower than in HCCI mode under the same engine conditions.

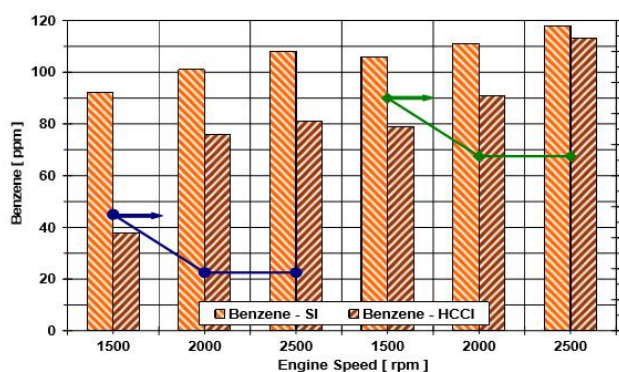


Figure (2) Benzene species at different engine speeds SI, HCCI

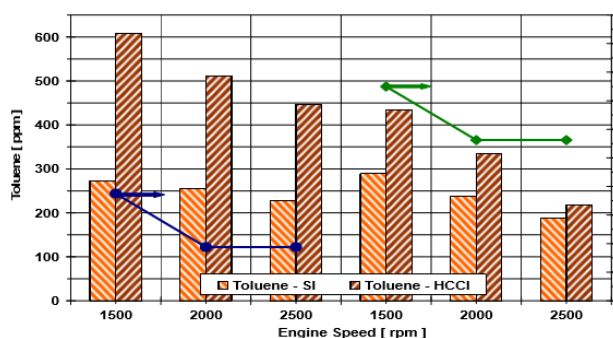


Figure (3) Toluene species at different engine speeds SI, HCCI

4. Conclusions

Exhaust hydrocarbons have been speciated, Species such as , benzene, are mainly found in the engine exhaust during SI engine operation, while heavier species such as Toluene are presented in higher concentrations under stoichiometric HCCI engine operation , HC emissions, , rise significantly in this region, which is very probably due to incomplete combustion. Data obtained on the contribution of C5 - C11 (indicator of the amount of unburned fuel) to the total exhaust hydrocarbons with variation in engine speed and for both SI and HCCI modes. The C5 – C12 ratio is frequently used to describe the extent to which fuels burn in an engine. In this investigation, it was found that in HCCI mode the proportion of species attributed to C5 – C11 in total HC is higher than in the SI mode.

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