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Original scientific paper

SIMULATION OF AN ACTUATOR & DRIVE OF A WIRE DRAWING MACHINE'S MECHATRONIC SYSTEM USING MATLAB/SIMULINK

Goce Tasevski, Zlatko Petreski, Dejan Šiškovski

Institute for Mechanics, Faculty of Mechanical Engineering, "Ss. Cyril and Methodius" University in Skopje, P.O. box 464, 1000 Skopje, Republic of Macedonia
goce.tasevski@mf.edu.mk

A b s t r a c t: Simulation of a mechatronic system actuator, implemented in a wire drawing machine, developed in Matlab/Simulink environment is presented in this paper. AC induction motor with vector control drive is chosen as an actuator. Mathematical model of the actuator is expressed in *d-q* reference frame rotating at synchronous speed. Diagrams for calculation of the important parameters for the simulation of the actuator were constructed. Simulation results from the model behaviour were discussed in comparison with the specified parameters by the manufacturer of the existing actuator integrated in such mechatronic system.

Key words: actuator; induction motor; simulation; Matlab/Simulink; mechatronic system

СИМУЛАЦИЈА НА АКТУАТОР ОД МЕХАТРОНИЧКИ СИСТЕМ НА МАШИНА ЗА ИЗВЛЕКУВАЊЕ НА ЖИЦА СО УПОТРЕБА НА MATLAB/SIMULINK

А п с т р а к т: Направена е симулација и анализа на динамичкото однесување на еден актуатор од мехатроничкиот систем на машина за извлекување на жица со употреба на Matlab/Simulink. Како актуатор е избран АС индукционен мотор со векторско управување. Математичкиот модел на актуаторот е претставен во референтен систем *d-q* кој ротира со синхрона брзина. Направени се дијаграми за пресметка на важните параметри за симулација на актуаторот. На крајот се дискутирани резултатите од симулацијата во споредба со дадените параметри од производителот за постојниот актуатор вграден во таков мехатронички систем.

Клучни зборови: актуатор; индуктивен мотор; симулација; Matlab/Simulink; мехатронички систем

1. INTRODUCTION

Improving performance of wire drawing machines, in terms of high drawing speed, has been usually achieved by the advances in the area of the die materials [1]. With the development of the mechatronic systems and functionalities nowadays, wire drawing machines could also increase the performances by introducing modern sensors and control units in the system itself. With better monitoring of the motor parameters new advanced control algorithms could be developed in order to better control the system behaviour and increase drawing speeds.

Mechatronic system of a modern wire drawing machine is presented in Figs.1 and 2. Dancer arms or tuner rolls are used as sensors to indicate the current tension in the wire. These signals values are compared with reference position values pre-set in the PLC controller. If any error occurs, PID controller together with variable frequency controllers gives command signals to the actuators, which are responsible for transforming the output of the control system into a controlling action on the mechanical system [2], [3], in order to maintain the wire tension.

One of the most important parts in the wire drawing machines are the motors that drive the blocks with different speeds to reduce the wire diameter. To increase performance of the machine, it is extremely important to develop a model of the entire system including the motors themselves, so

that the engineers have clear picture of the parameter influence during the wire production. Choosing the right motor type for this technology remained an engineering challenge even today.

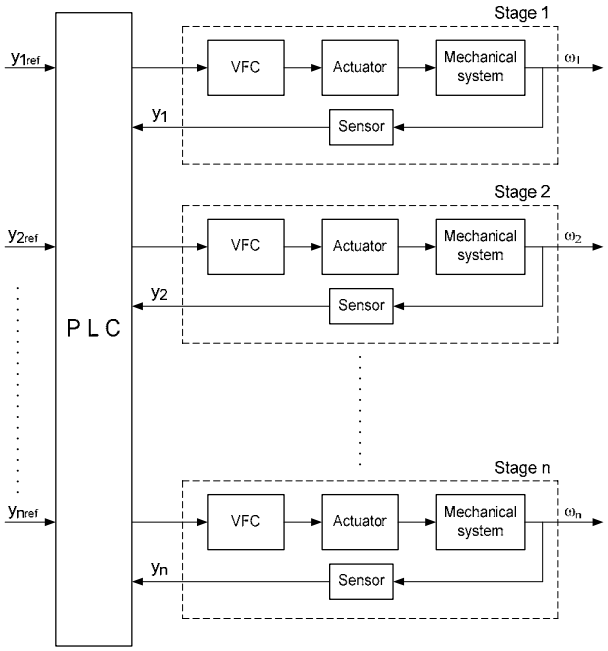

Fig. 1. Mechatronic system of a wire drawing machine

Green and Kramer [4] have compared the differences between AC and DC actuators applied to the wire drawing machines in terms of line speed, dancer control, efficiency and power consumption, and maintenance. They have pointed out that modern AC drives with advanced vector control algorithms are able to offer performances which are as good as equivalent DC drive. Therefore, AC actuators and drives are making serious inroads into applications where previously only DC actuators would have been considered.

Matlab/Simulink is established engineering tool when it comes to modelling of dynamic systems. Here, as well, this platform has been used to simulate a vector controlled AC induction motor, as an actuator from wire drawing machine. Input motor parameters that will be used in simulation, such as nominal power, nominal speed, nominal voltage and nominal frequency, given by the manufacturer, are shown in Table 1.

In this paper, in section 2, the actuator mathematical model is developed in detail. The Matlab/Simulink implementation is given in section 3, and in section 4 the simulation results are presented. At the end some conclusions and final remarks are given.

T a b l e 1

Parameters from AC induction motor's nameplate

Induction motor parameters	Value
Nominal power	30 kW
Nominal voltage	380 V
Nominal frequency	50 Hz
Nominal current	56.6 A
Nominal speed	1468 rpm
Electromagnetic torgue	190.9 N m

2. ACTUATOR MODEL

AC induction motors could be mathematically modelled in many different ways. The model used in this paper utilizes the concept of vector control, which is the most popular control technique of AC induction motors. The concept of vector control is based on the methodology of control of separately excited DC motors, where field flux produced by the field current is perpendicular to the armature flux produced by the armature current. Vector control seeks to recreate these orthogonal components in the AC machine in order to control the torque producing current separately from the magnetic flux producing current [5]. This control is usually performed in the reference frame (*d*-*q*) attached to the rotor flux space vector. Analysis and design of the induction motor is traditionally done through the per-phase equivalent circuit [6], [7], shown in Figures 2 and 3.

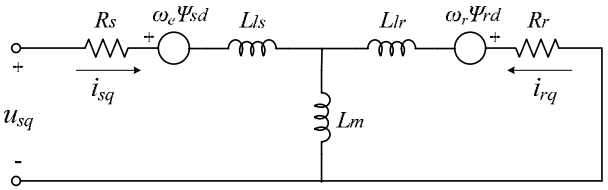

Fig. 2. *q*-axis circuit

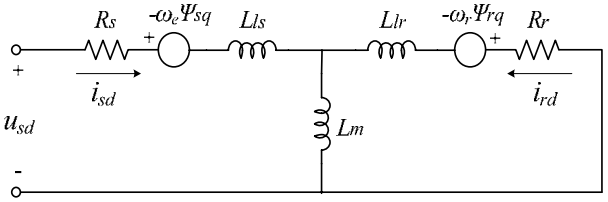

Fig. 3. *d*-axis circuit

In Figures 2 and 3, *Rs* and *Rr* represent the stator and rotor winding resistances, *Lm* is the

magnetizing inductance of the motor and *Lls* and *Llr* are the stator and rotor leakage inductances.

Considering the direct and quadrature axis (*d-q*) reference frame rotating at synchronous speed ω_e, the model of the induction machine, as stated in [8] and [9], is given by the following equations:

Stator voltage equations:

$$u_{sd} = R_s i_{sd} + \frac{d}{dt}\Psi_{sd} - \omega_e \Psi_{sq}$$
$$u_{sq} = R_s i_{sq} + \frac{d}{dt}\Psi_{sq} + \omega_e \Psi_{sd} \quad (1)$$

Rotor voltage equations:

$$u_{rd} = 0 = R_r i_{rd} + \frac{d}{dt}\Psi_{rd} - (\omega_e - \omega_r)\Psi_{rq}$$
$$u_{rq} = 0 = R_r i_{rq} + \frac{d}{dt}\Psi_{rq} + (\omega_e - \omega_r)\Psi_{rd} \quad (2)$$

Stator and rotor flux linkage equations:

$$\Psi_{sd} = L_s i_{sd} + L_m i_{rd}$$
$$\Psi_{sq} = L_s i_{sq} + L_m i_{rq}$$
$$\Psi_{rd} = L_r i_{rd} + L_m i_{sd} \quad (3)$$
$$\Psi_{rq} = L_r i_{rq} + L_m i_{sq}$$

Electromagnetic torque:

$$T_e = 1.5p\frac{L_m}{L_r}\left(\Psi_{rd} i_{sq} - \Psi_{rq} i_{sd}\right) \quad (4)$$

3. MATLAB/SIMULINK IMPLEMENTATION

A standalone 3-phase induction motor with vector control drive is simulated in this part of the paper. The motor model is needed for more accurate modelling of the complex wire drawing machine's mechatronic system. Establishing accurate model of the mechatronic system is essential in increasing performances of the machine. As the motor being one of the main components of the mechatronic system, modelling the motor that would be implemented in the machine is challenge by itself.

The motor modelled for the purpose of this paper has the following characteristics stated by the manufacturer: nominal power of the actuator is 30 kW, AC source phase-to-phase rms voltage value is 380 V, and the frequency is 50 Hz. The idea of the model and simulation is to confirm the motor parameters (nominal current, nominal speed and electromagnetic torque) given by the manufacturer, shown in Table 1. Matlab/Simulink model of the actuator, based on the mathematical model developed in section 2 is presented in Figure 4.

To develop the model in MATLAB/Simulink, electrical and mechanical parameters of the motor are required. Based on the data given by the manufacturer, it was concluded that those information are not sufficient to estimate the basic parameters of the motor needed to be imported in the MATLAB/Simulink model. Since it has been used a motor that has power 30 kW, with no detailed information, it was decided to find this values based on the following methodology.

MATLAB/Simulink library contains a limited set of induction motor models with prescribed nominal power. Using the data of the existing models, diagrams for rotor and stator resistance, leakage stator and rotor inductance, mutual inductance, inertia and friction coefficient, in relation to the motor power were constructed and are given below in Figures 5 to 10. Trend lines were used in order to obtain mathematical expressions that are used to calculate the values of the necessary parameters.

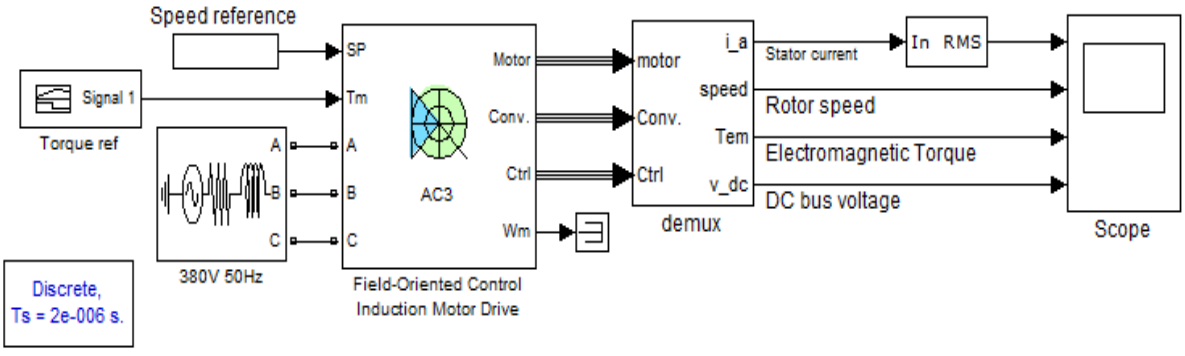

Fig. 4. Matlab/Simulink model of AC induction motor

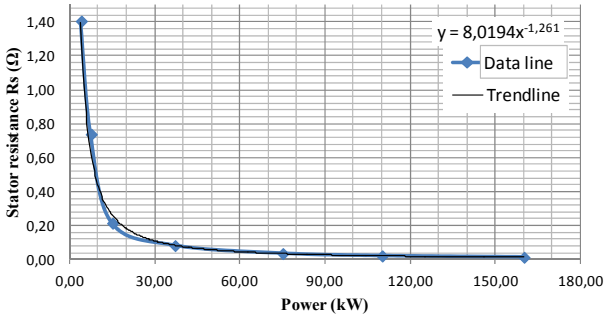

Fig. 5. Determination of stator resistance *Rs*

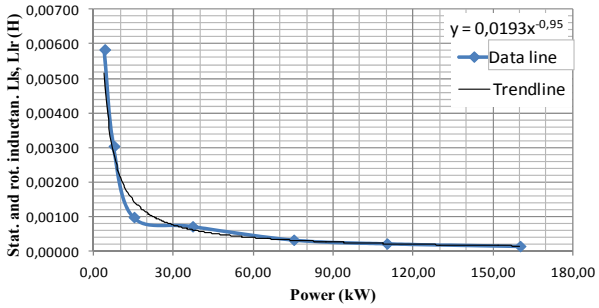

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Fig. 6. Determination of stator and rotor inductances *Lls, Llr*

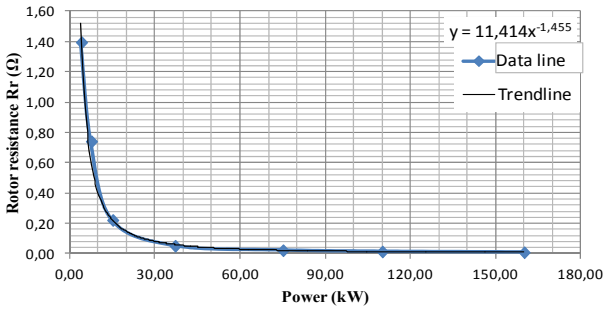

Fig. 7. Determination of rotor resistance *Rr*

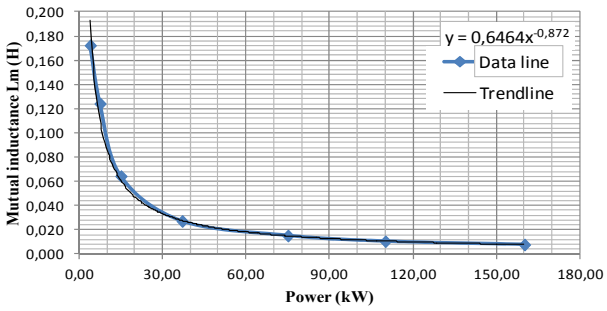

Fig. 8. Determination of mutual inductance *Lm*

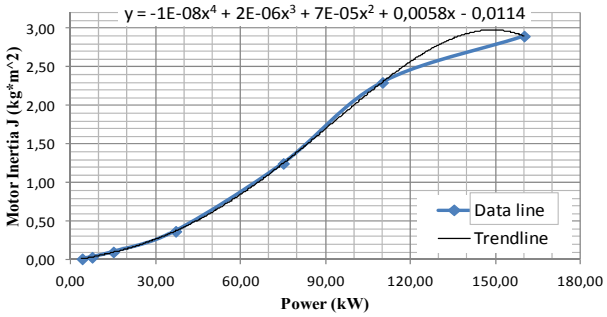

Fig. 9. Determination of motor inertia *J*

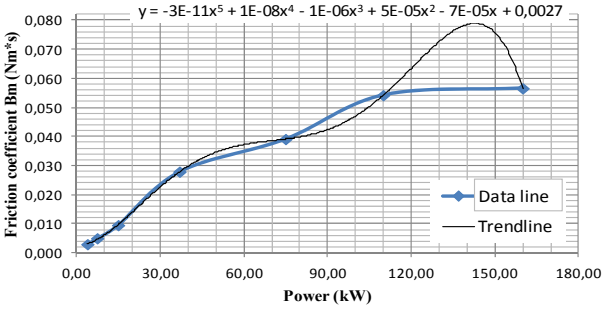

Fig. 10. Determination of friction coefficient *Bm*

Based on the diagrams for determination of the motor parameters, the parameters for the 30 kW motor were extracted and are given in Table 2.

Table 2

Electrical and mechanical parameters of the simulated actuator model

Motor parameters	Value
Stator resistance	0.11 Ω
Rotor resistance	0.0809 Ω
Leakage stator inductance	0.000762 H
Leakage rotor inductance	0.000762 H
Mutual inductance	0.0333 H
Inertia	0.02715 kg·m^2
Friction	0.025971 Nm·s

In the model, load torque was selected as a mechanical input in order to get the actuator speed as output, based on the following differential equation, which describes the mechanical system dynamics [10],

$$T_e = J\frac{d}{dt}\omega_r + B\omega_r + T_m \tag{5}$$

where J – motor inertia; ω_r – rotor speed; T_e – electromagnetic torque; T_m – load torque; $B{\cdot}\omega_r$ – friction torque.

General scheme of the induction motor's drive is shown in Figure 11.

Reference speed of the actuator is set point in the Matlab/Simulink model. The rest of the settings used in the model are given in Table 3.

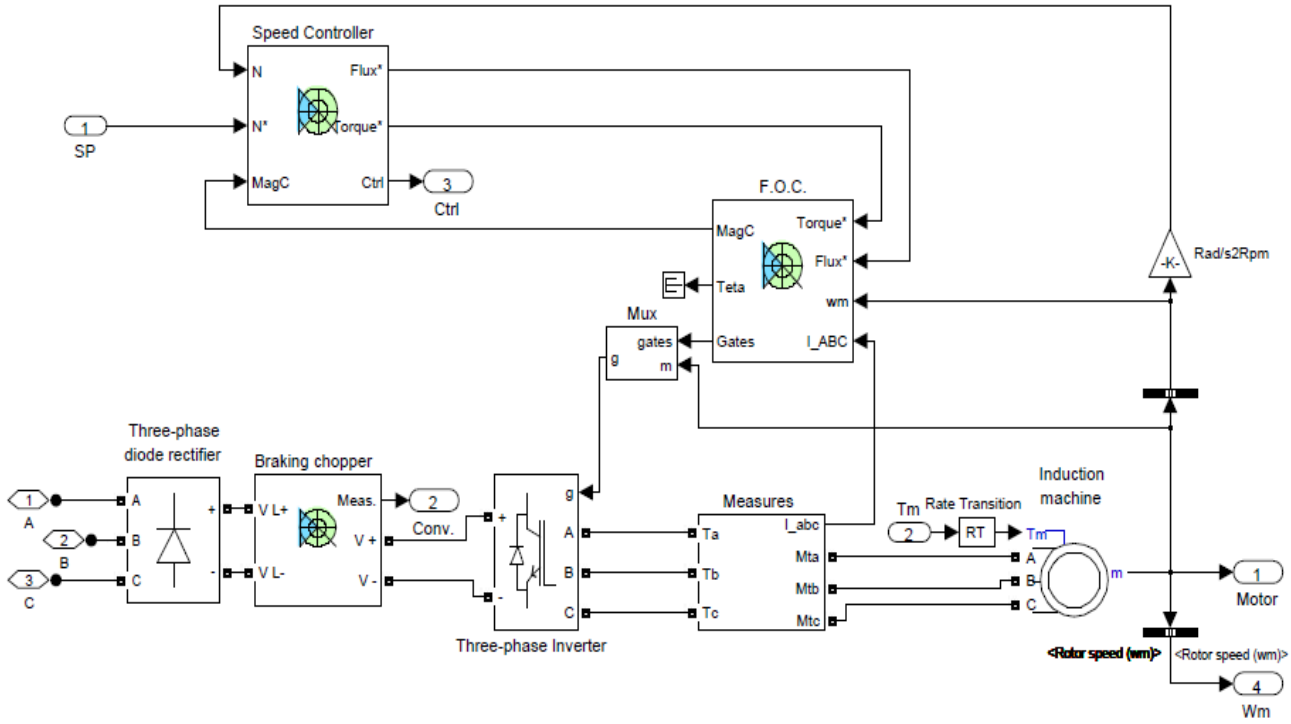

Fig. 11. Scheme of induction motor's drive

The dynamic response of the rotor speed and electromagnetic torque can be adjusted by the proportional and integral gains from the PI controllers in the speed and flux controllers. Speed controller and field oriented controller schemes are shown in Fig. 12 and Fig. 13, while Fig. 14 shows flux controller scheme. Tuning the parameters from speed and flux PI controllers is done by using trial and error method, and best fit parameters are inserted in Table 3, as well.

Table 3

Parameters for speed and flux controller

Speed controller parameters	Value
Acceleration ramp	500 rpm/s
Deceleration ramp	500 rpm/s
Proportional gain	10
Integral gain	2000
Flux controller prameters	Value
Proportional gain	50
Integral gain	200

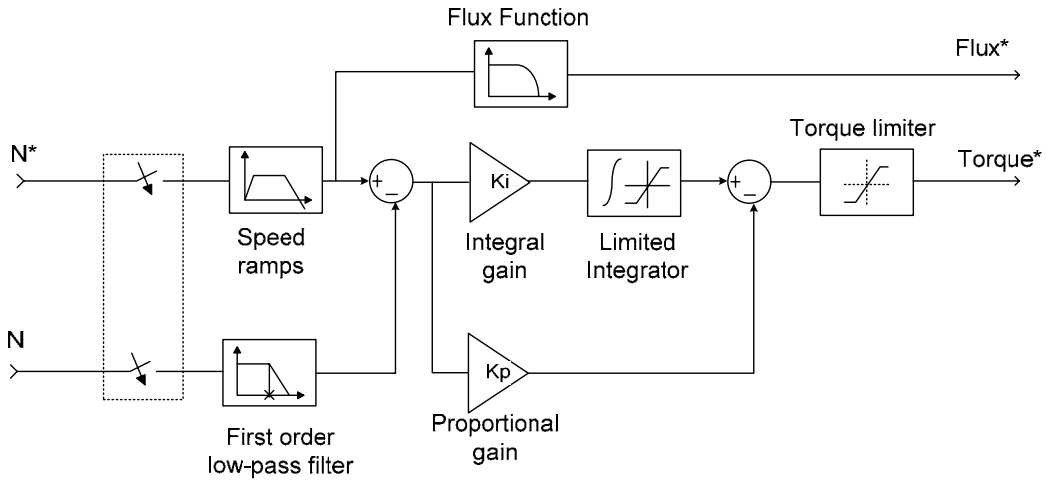

Fig. 12. Scheme of speed controller

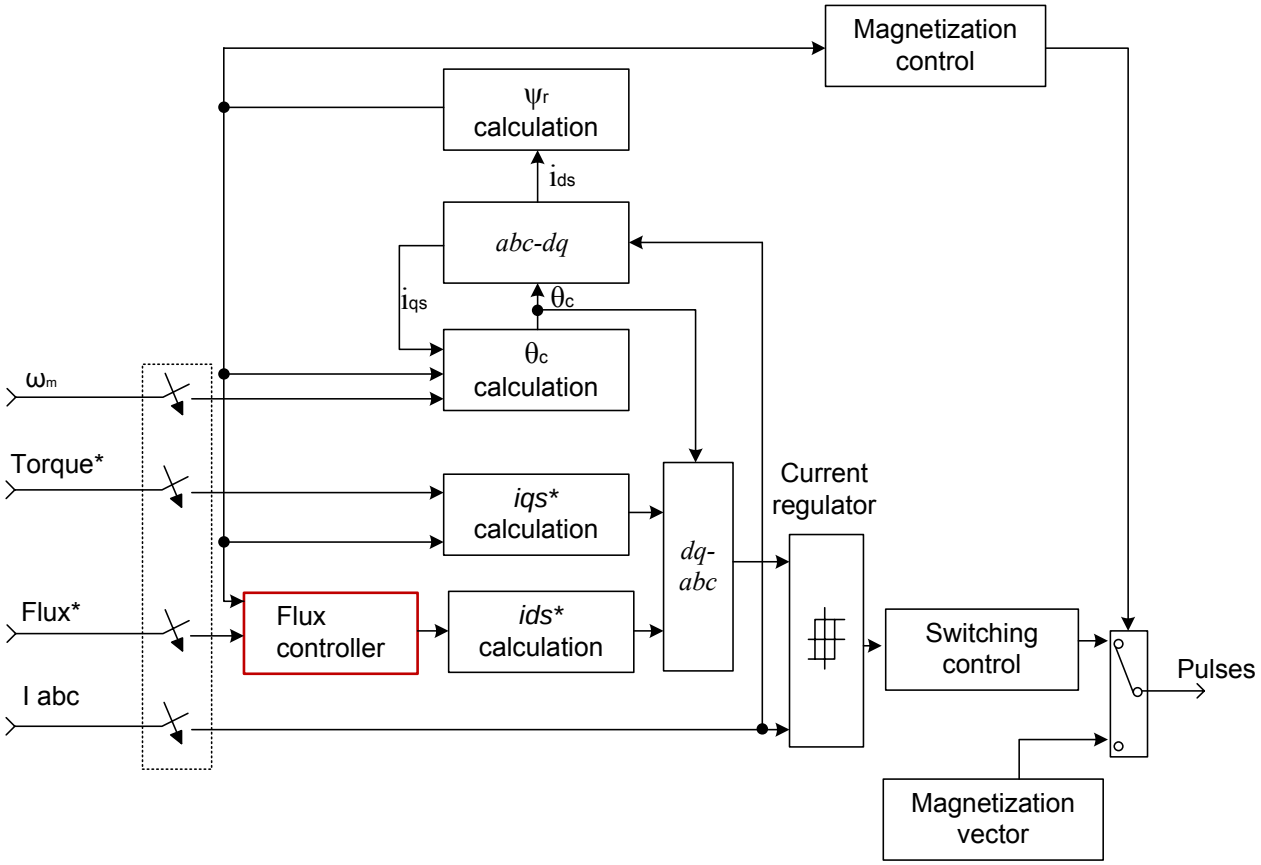

Fig. 13. Scheme of field oriented controller

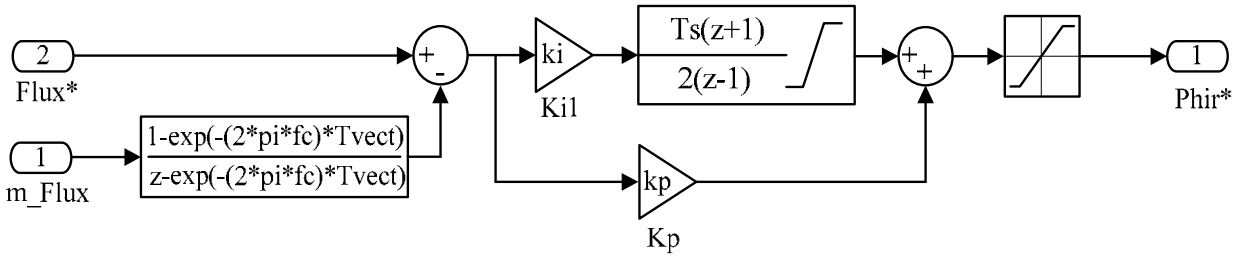

Fig. 14. Scheme of flux controller

4. SIMULATION RESULTS

The simulation of the motor behaviour was done in the Simulink environment and the results are given in Fig. 15.

At time t = 0 s, the speed set point value is 1468 rpm. Applied load torque should reach 190 Nm at t = 3 s, after that period, maintained a constant value.

The actuator reaches its maximum speed in little less than 3 s, according to the acceleration ramp which is set to 500. Static error of the speed is reduced in range from 0.05 to 0.1 rpm due to the large integral gain of the speed controller so the reference and actual rotor speed of the actuator is identical (second diagram from Figure 15).

Stator current oscillates while the load torque reaches its set point value at t = 3 s. Then, it maintains a value of 60 A. Differences between load torque and electromagnetic torque can be reduced by adjusting the flux controller parameters.

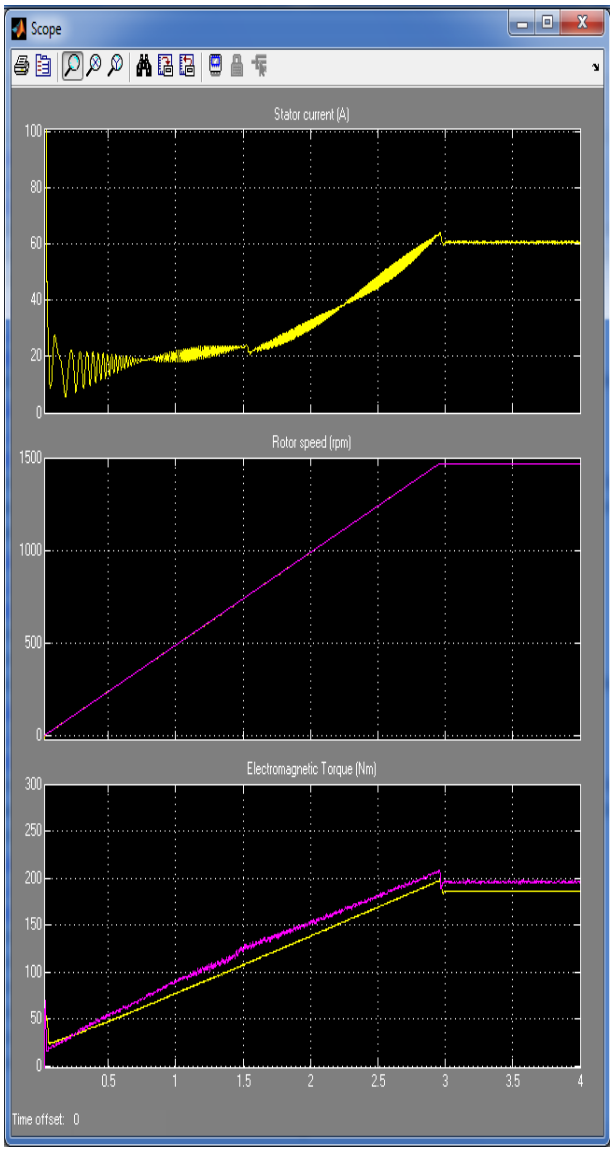

Fig. 15. Results from the simulation

5. CONCLUSIONS

In this paper an actuator and drive from a wire drawing machine's mechatronic system were simulated using Matlab/Simulink. Matlab/Simulink environment was tested and proven to be powerful tool in the process of modelling and analyzing dynamic behavior of induction motor.

The necessary parameters for the simulation were obtained by constructed diagrams based on existing previously defined motor models in Matlab/Simulink library.

The simulation results were compared with the manufacturer data given in the specification of the motor. For the proposed input values: nominal power, nominal voltage, nominal frequency and nominal speed, the output values for the nominal current, the electromagnetic torque and the rotor speed are in sufficient accuracy range with the value prescribed from the manufacturer.

Modelling the motor behavior, as accurate as possible, is important task that allows developing complex models of mechatronic systems. By confirming the motor parameters, as shown in this paper, a solid model of the motor behavior has been constructed and could be upgraded with the other functional blocks.

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Original scientific paper

COMPARISON OF CONTACT SKIDDED AND SKIDLESS TECHNIQUES WHICH ARE USED FOR SURFACE ROUGHNESS CHARACTERIZATION

Mite Tomov[1], Piotr Cichosz[2], Mikolaj Kuzinovski[1]

[1]*"Ss. Cyril and Methodius" University in Skopje, Faculty of Mechanical Engineering, Karpoš II bb, P.O. box 464, 1001 Skopje, Republic of Macedonia*
[2]*Institute of Production Engineering and Automation of the Wrocław University of Technology, Str. Lukasiewicza 3/5, 50-371 Wrocław, Polska*
mikolaj.kuzinovski@mf.edu.mk

A b s t r a c t: In this study included several dilemmas arising from the recommendations in the international standards referring to surface roughness measurement with using skidded and skidless measurement instruments. Also, this paper explained the role and the impact of the skid as mechanical reference in the construction of the surface roughness measuring instruments. In order to determine the impact from the different constructive performances of the measurement instruments on the surface roughness value, are measured more periodic and non-periodic etalon surfaces representative of various machining process (turning, milling, grinding and lapping). Comparative analysis of the values and differences for the roughness parameters and primary profile parameters are displayed.

Key words: primary profile parameters; roughness parameters; skidded instruments; skidless instruments; periodic and non-periodic etalon surfaces

СПОРЕДБА НА КОНТАКТНИТЕ ТЕХНИКИ СО ЛИЗГАЧ И БЕЗ ЛИЗГАЧ КОИ СЕ КОРИСТАТ ЗА КАРАКТЕРИЗАЦИЈА НА РАПАВОСТА НА ПОВРШИНИТЕ

А п с т р а к т: Со оваа истражување се опфатени неколку дилеми кои произлегуваат од препораките во интернационалните стандарди, а кои се однесуваат на мерењето на рапавоста на површините со користење на мерни инструменти со лизгач и без лизгач. Во овој труд исто така се објаснетаиулогата и влијанието на лизгачот како механичка референца во конструкцијата на инструментите за мерење на рапавоста на површините. Мерени се повеќе периодични и непериодични еталон-површини претставници на различни обработки (стружење, глодање, брусење и зглобување), а со цел да се определи влијанието врз вредностите на параметрите на рапавоста кое произлегува од различните конструктивни изведби на мерните инструменти. Прикажана е компаративна анализа на вредностите и нивните разлики за параметрите на рапавост и параметрите на примарниот профил.

Клучни зборови: параметри на примарен профил; параметри на рапавост; инструменти со лизгач; инструменти без лизгач; периодични и непериодични еталон-површини

1. INTRODUCTION

The procedure (procedures) for obtaining the roughness profile, and thereby the roughness parameters, has evolved together with the increase of the capacities of measuring devices. In order to provide the conditions for comparability of the measured values of the roughness parameters, the procedures and recommendations used to measure and obtain the roughness profile are usually in-

cluded in national standards on local level, or international standards on global level, which are usually harmonized with one another. However, these procedures and recommendations to be applicable for different types of measuring instruments, they are general. According to ASME B46.1-2009 [1] all instruments that measure surface texture can be grouped into six groups of instruments (first: profiling contact skidless instruments, second: profiling non-contact instruments, third: scanned probe microscopy, fourth: profiling contact skidded instruments, fifth: skidded instruments parameters only, and sixth: area averaging instruments). Of all the mentioned groups of measuring instruments for application purposes are used mostly contact skidded or skidless measuring instruments.

The main purpose of these researches is to determine whether there are any differences as well as the size of those differences between the values of the roughness parameter obtained using two contact different measuring instruments (skidded and skidless), when measuring periodic and non-periodic etalon surfaces in identical measuring conditions.

2. THE FUNDAMENTAL DIFFERENCES BETWEEN SKIDDED AND SKIDLESS INSTRUMENTS

The skids from skidded instruments have a role of a mechanical reference used to register the vertical movement of the measuring stylus. The skid also has a role of a mechanical separator (a mechanical filter) of the roughness profile from the surface (total) profile (Fig. 1). On the other hand, the skid can contribute to a drastic change in the form of the measured profile (Fig. 2).

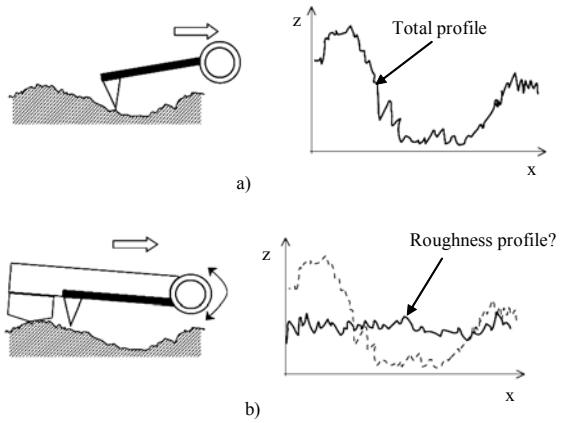

Fig. 1. The role of the skid
a) skidless instruments, b) skidded instruments [2]

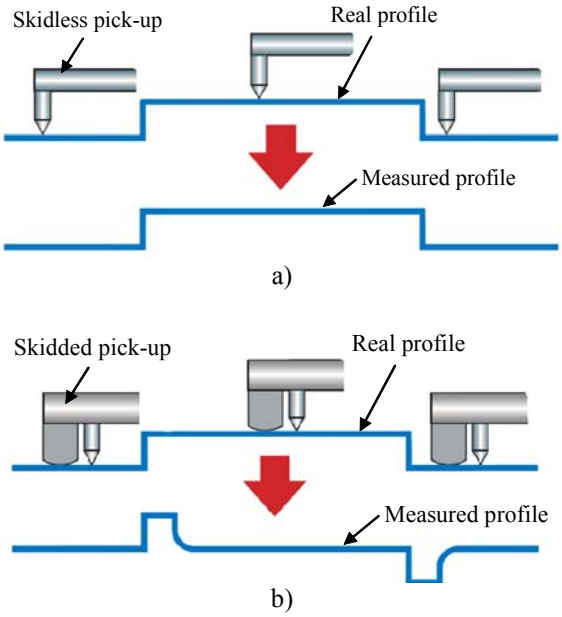

Fig. 2. Change to the shape of the measured profile as a result of the skid
a) skidless instruments, b) skidded instruments [3]

Although the deviations (change) of the measured profiles, shown on Figures 2, are on the micro (or meso) level, still it is useful to research these impacts since the contact surface between the measured surface and the skid, for certain constructions, is very small. One pick-up can contain several skids. It is recommended to place the skid in close proximity to the measuring stylus, before or after the stylus, or the measuring stylus can pass through the middle of the skid. Each different constructive shape of the skid and his positioning combinations (before or after the measuring stylus) influences the shape of the measured profile. Usually the shape and the position of the skid (skids) depend on the type of the pick-up (pick-up for the deep groove, pick-up for the curved surface etc.). In this context, the International standards lack recommendations about the metrological characteristics of the geometry of the contact segment of the skid. Simply, according to ISO 3274:1996 [4], if the skid has spherical shape, its radius in the direction of the trace should be no less than 50 times of the nominal cut-off wavelength used.

In [5] is presented a detailed illustration of the measuring procedure for obtaining the roughness profile and the roughness parameters using contact skidless instruments, in accordance with the recommendations of several international standards. In addition, [2] stipulates certain ambiguities arising from the international standards. According to ISO 3274:1996 [4], instruments using skids can be

used for measuring roughness parameters only. On the other hand, the calculation of the values of the roughness parameters requires the determination of a mean reference line using a λc profile-filter, which means that the measured profile should undergo software filtration using a λc profile filter. How do we call the profile through which we draw the mean reference line using a λc profile filter**?** Is this the primary profile? Also, having in mind that it is not possible to isolate the noise from the signal during the measurement, again there is a need for software filtration using a λs profile filter. If we add the noise to the primary profile, do we get the total profile? Every measuring instrument has a λs profile-filter, and usually, in the case of portable instruments, this filter turns on automatically, without any activation by the metrologist. If, on top of this, we also add the software leveling of the measured profile (using the least squares method) which is the same as removing the nominal linear shape, then we get the total profile. Therefore, the question is: What kind of an initial profile is obtained when the using an instrument that uses a skid as a mechanical reference?

Precisely these remarks, directly related to the use of contact skidded and skidless instruments were the additional reason to implement this type of research.

3. EXPERIMENTAL INVESTIGATIONS

3.1. *Measuring conditions*

The research includes several periodic and non-periodic etalon surfaces representing various processes such as turning, milling, grinding (circular and flat) and lapping. In order to enable the measuring stylus to traverse an approximately equal path on the etalon-surface, the place where the measurement starts (the starting point of the measuring stylus) was marked on the etalons. The measurements were done using a contact measuring system MarSurf XR20 (with MarSurf XR20 V1.30-5 software) as a skidless measuring system and the contact profilemeter Surtronik 3+ (with the TalyProfile V3.1.4 software) as the skidded measuring instrument. Both measuring systems used a measuring stylus with a tip radius of 2 μm. The measuring conditions (the sampling length, evaluation length, sampling spacing etc.) are compliant with the recommendations from the international standards and the recommendations from [5], and they are identical when using either of the two instruments. The measuring instruments in this research were used only to obtain the coordinates of the measures (total) profiles. The nominal form was removed using the Microsoft Excel software and the least square method, while the filtering was done using λc and λs profiles filters and the Matlab (R2009b) using the mathematical formulations provided in ISO 11562:1996 [6] and ISO 16610-21:2011 [7] for the weight functions of the profile filters. The Gaussian filter was used as the λc profile filter. The obtained data (the total profile coordinates) were processed outside of the MarSurf XR20 V1.30-5 software and the TalyProfile V3.1.4 software in order to provide for identical conditions for data processing. Both measuring instruments were calibrated using the type C standard [8], in accordance with [9].

Considering the ambiguities present in the international standards, stipulated in [2], the authors of this paper have adopted two methods (cases) for obtaining the roughness profile using the contact profilemeter Surtronik 3+.

First case: In the case the measured profile shall be considered to be the roughness profile.

Second case: In this case the measured profile shall be considered to be the total profile, as if it were measured with a skidless instrument.

3.2. *Results and discussion*

The differences between the roughness parameters (the primary profile parameters) measured using the two different measuring instruments are shown on Figures 3 to 22. The research includes the following parameters: SE (Parameter of statistic equality ot sampling lengths [5]), Ra (Pa), Rt (Pt), Rq (Pq) and RSm (PSm). The values of the considered parameters were obtained as the average of five measurements.

The values of the considered parameters obtained using Surtronik 3+, shown on Figures 3 to 12, were calculated for the case when the measured profile is considered to be the roughness profile. Therefore the comparison does not include the P-parameters (the primary profile parameters), which is not the case for the Figures 13 to 22 when the profile measured using Surtronik 3+ is considered to be the total profile from which is obtained the roughness profile.

The presented diagrams suggest that there are significant difference between the valued obtained using the two different measuring instruments.

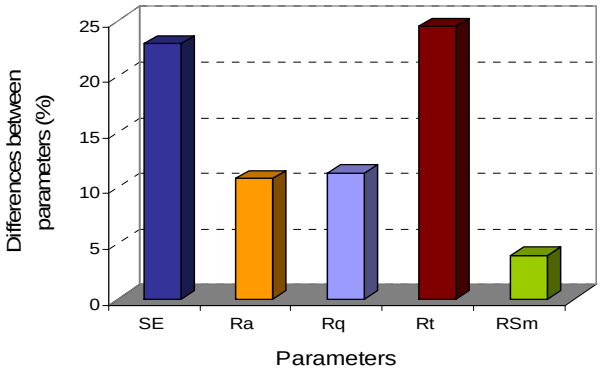

Fig. 3. Differences between parameters for the etalon surface representative of turning with Ra = 1.8 μm

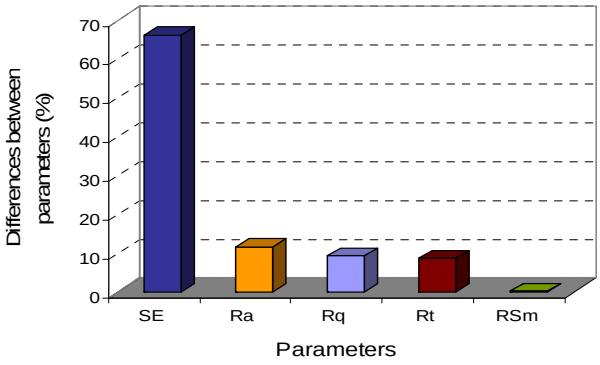

Fig. 4. Differences between parameters for the etalon surface representative of turning with Ra = 3.2 μm

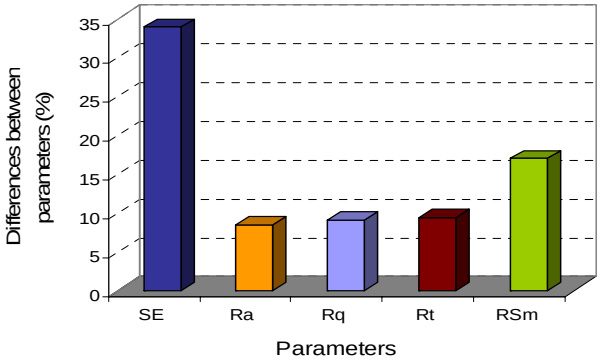

Fig. 5. Differences between parameters for the etalon surface representative of milling with Ra = 1.6 μm

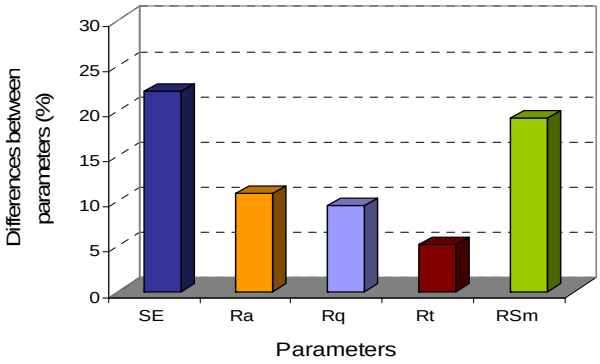

Fig. 6. Differences between parameters for the etalon surface representative of milling with Ra = 3.2 μm

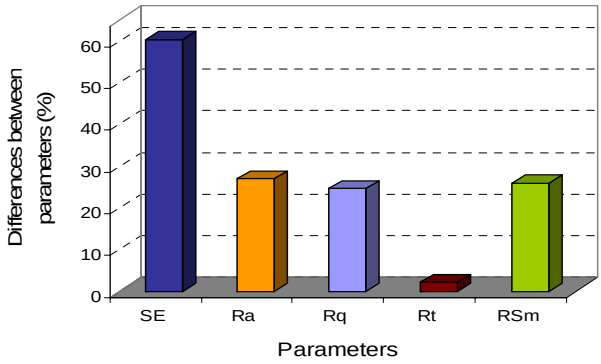

Fig. 7. Differences between parameters for the etalon surface representative of circular grinding with Ra = 0.2 μm

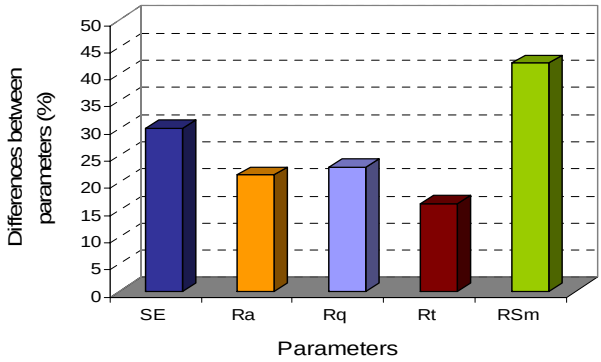

Fig. 8. Differences between parameters for the etalon surface representative of circular grinding with Ra = 0.8 μm

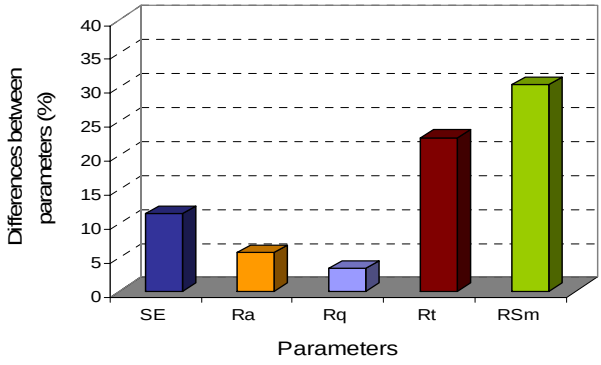

Fig. 9. Differences between parameters for the etalon surface representative of flat grinding with Ra = 0.4 μm

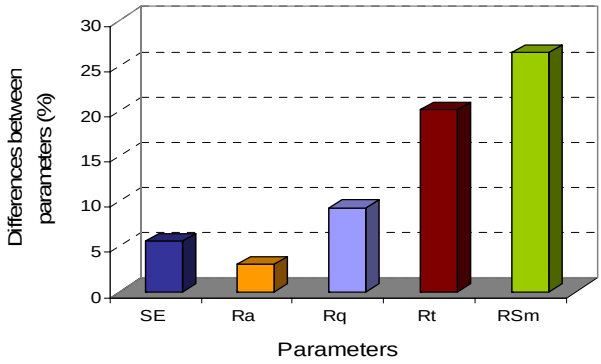

Fig. 10. Differences between parameters for the etalon surface representative of flat grinding with Ra = 0.8 μm

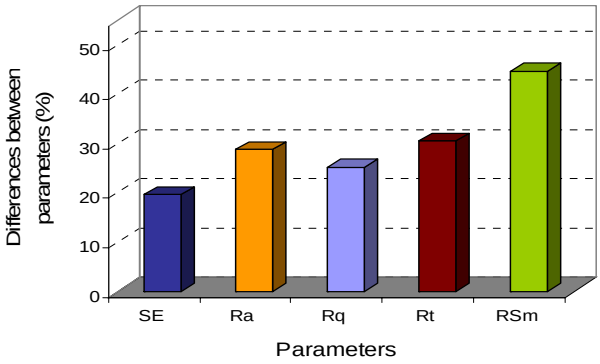

Fig. 11. Differences between parameters for the etalon surface representative of lapping with Ra = 0.05 μm

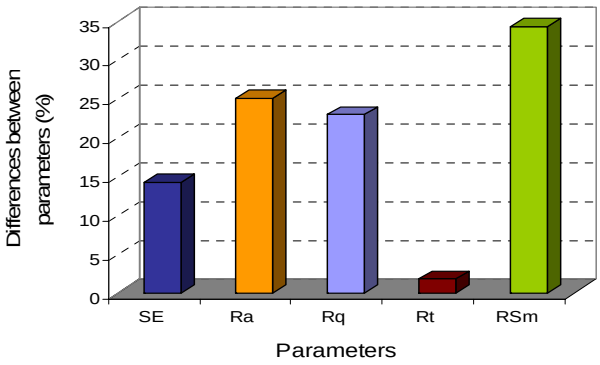

Fig. 12. Differences between parameters for the etalon surface representative of lapping with Ra = 0.2 μm

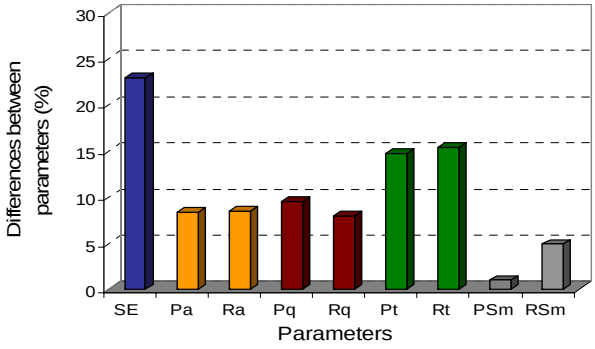

Fig. 13. Differences between parameters for the etalon surface representative of turning with Ra = 1.8 μm

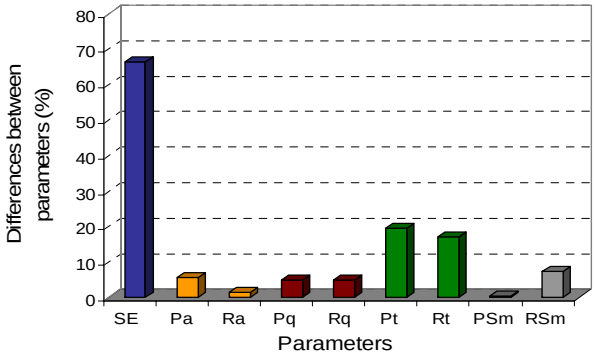

Fig. 14. Differences between parameters for the etalon surface representative of turning with Ra = 3.2 μm

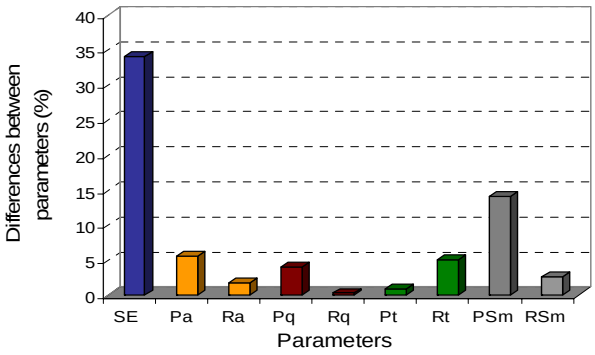

Fig. 15. Differences between parameters for the etalon surface representative of milling with Ra = 1.6 μm

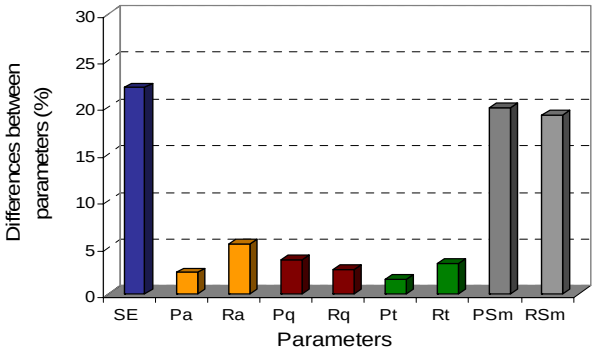

Fig. 16. Differences between parameters for the etalon surface representative of milling with Ra = 3.2 μm

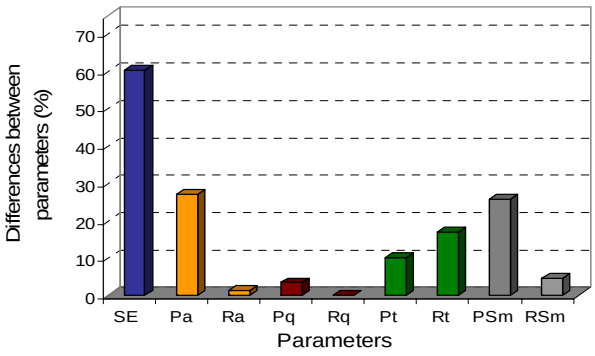

Fig. 17. Differences between parameters for the etalon surface representative of circular grinding with Ra = 0.2 μm

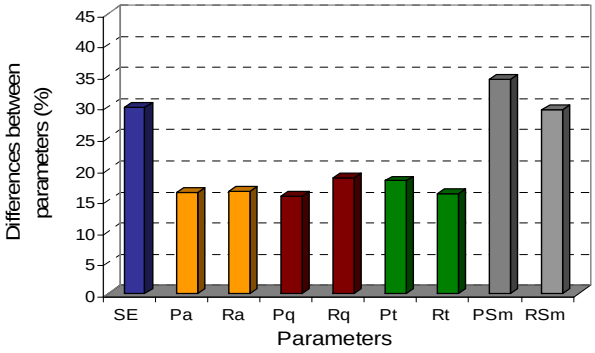

Fig. 18. Differences between parameters for the etalon surface representative of circular grinding with Ra = 0.8 μm

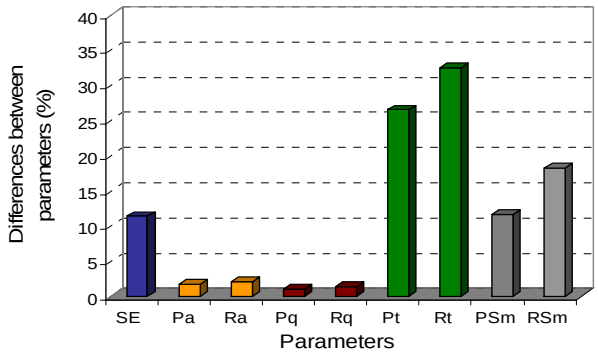

Fig. 19. Differences between parameters for the etalon surface representative of flat grinding with Ra = 0.4 μm

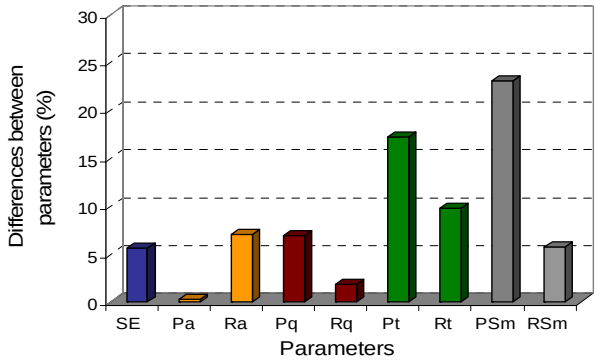

Fig. 20. Differences between parameters for the etalon surface representative of flat grinding with Ra = 0.8 μm

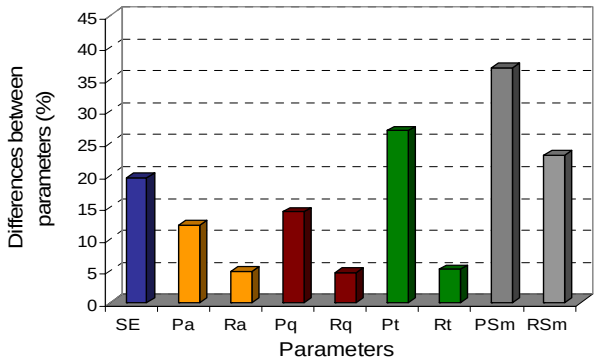

Fig. 21. Differences between parameters for the etalon surface representative of lapping with Ra = 0.05 μm

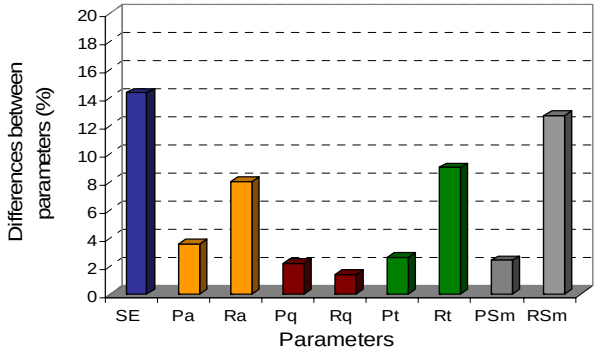

Fig. 22. Differences between parameters for the etalon surface representative of lapping with Ra = 0.2 μm

The biggest differences can be noted for the SE parameter (the parameter of statistic equality of sampling lengths), especially for periodic profiles (turning and milling). The significant differences of the SE parameter suggest that the profile forms are different after all.

If we compare the values of differences between the parameters obtained in the first and the second case, we can conclude that the differences are smaller in the second case, when the measured profile is considered to be the total profile. This is a very important conclusion that suggests that the recommendations in the international standards referring to the skidded instruments need to be further specified in the future. If we compare the differences between the primary profile parameters (P-parameters) and the roughness profile parameters (R-parameters), shown on Figures 13 to 22, we can conclude that no specific pattern exists. For some of the profiles the P-parameter differences are larger, whereas the R-parameters are larger for other profiles.

The authors may have expected to see that the parameter RSm exhibited quite significant differences. This can be explained as follows:

a) The horizontal sampling spacing of the measuring instruments is obtained as result of reconciling the speed of the pick-up along the surface during the measuring process and the sampling speed of the A/D converter. The differences of the horizontal sampling spacing will have a direct impact on the value of the RSm and the PSm parameters.

b) The change of the profile form results in the drawing of a new filter mean line which directly impacts the values of the RSm and the PSm parameters.

4. CONCLUSION

These researches showed that one needs to be very careful when using skidded instruments to obtain the roughness parameters. The differences between the roughness parameters obtained by fully complying with the recommendations contained in the international ISO standards arise primarily as a result of ambiguities in the definition of the measuring procedures. In order to overcome this situation, the surface roughness measuring procedures should be further specification The

large differences in the PSm (RSm) parameter lead us to the conclusion that maybe the calibration of the measuring instruments requires more than an overall calibration using one type of etalon, but rather calibration of the vertical readout of the instrument should be separated from the horizontal. The values obtained for the differences between the considered parameters have shown no specific change patters.

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Original scientific paper

NON-COLLOCATED FUZZY LOGIC AND INPUT SHAPING CONTROL STRATEGY FOR ELASTIC JOINT MANIPULATOR: VIBRATION SUPPRESSION AND TIME RESPONSE ANALYSIS

Mohammad Amin Rashidifar[1], **Ali Amin Rashidifar**[2]

[1]*Faculty of Mechanical Engineering, Islamic Azad University, SHADEGAN Branch, SHADEGAN, Iran,*
[2]*Computer Science, Islamic Azad University, SHADEGAN Branch, SHADEGAN, Iran*
rashidifar_58@yahoo.com // Shadegan_950@yahoo.com

A b s t r a c t: Conventional model-based control strategies are very complex and difficult to synthesize due to high complexity of the dynamics of robots manipulator considering joint elasticity. This paper presents investigations into the development of hybrid control schemes for trajectory tracking and vibration control of a flexible joint manipulator. To study the effectiveness of the controllers, initially a collocated proportional-derivative (PD)-type Fuzzy Logic Controller (FLC) is developed for tip angular position control of a flexible joint manipulator. This is then extended to incorporate a non-collocated Fuzzy Logic Controller and input shaping scheme for vibration reduction of the flexible joint system. The positive zero-vibration-derivative-derivative (ZVDD) shaper is designed based on the properties of the system. Simulation results of the response of the flexible joint manipulator with the controllers are presented in time and frequency domains. The performances of the hybrid control schemes are examined in terms of input tracking capability, level of vibration reduction and time response specifications. Finally, a comparative assessment of the control techniques is presented and discussed.

Key words: elastic joint; vibration control; input shaping; fuzzy logic control

ФАЗИЛОГИЧЕН УПРАВУВАЧКИ АЛГОРИТАМ СО ОФОРМУВАЊЕ НА ВЛЕЗОТ ЗА МАНИПУЛАТОР СО ЕЛАСТИЧНА ВРСКА: ПРИДУШУВАЊЕ НА ВИБРАЦИИ И АНАЛИЗА НА ВРЕМЕНСКИ ОДЗИВ

А п с т р а к т: Конвенционалните управувачки алгоритми базирани на модел се многу комплексни и тешки за креирање поради сложеноста на динамиката на манипулатори земајќи ја предвид еластичната врска. Овој труд презентира инстражувања од развој на хибридни управувачки алгоритми за следење на траекторија и контрола на вибрациите на манипулатор со еластична врска. За испитување на ефективноста на управувачот, најпрво е развиен PD-тип на фази-управувач за управување со аголната позиција на манипулаторот со еластична врска. Потоа овој концепт е проширен со вклучување фази-управувач и управувач со оформување на влезот за намалување на вибрациите на системот. Управувачот со оформување на влезот е проектиран според карактеристиките на системот. Резултатите од симулацијата се презентирани во временски и фреквенциски домен. Перформансите на хибридниот управувачки алгоритам се анализирани врз основа на способноста за следење, нивото на намалување на вибрациите и временскиот одзив. На крајот е презентирана и дискутирана компаративна анализа на управувачките техники.

Клучни зборови: еластична врска, контрола на вибрации, управување со оформување на влез, управување со фази-логика

1. INTRODUCTION

Nowadays, elastic joint manipulators have received a thorough attention due to their light weight, high manoeuvrability, flexibility, high power efficiency, and large number of applications. However, controlling such systems still faces numerous challenges that need to be addressed.

The control issue of the flexible joint is to design the controller so that link of robot can track a prescribed trajectory precisely with minimum vibration to the link. In order to achieve these objectives, various methods using different technique have been proposed. Yim [1], Oh and Lee [2] proposed adaptive output-feedback controller based on a backstepping design. This technique is proposed to deal with parametric uncertainty in flexible joint. The relevant work also been done by Ghorbel et al. [3]. Lin and Yuan [4] and Spong et al. [5] introduced non linear control approach using namely feedback linearization technique and the integral manifold technique respectively. A robust control design was reported by Tomei [6] by using simple PD control and Yeon and Park [7] by applying robust H_∞ control. Among the proposed techniques, the conventional feedback control design handled by pole placement method and LQR method also have been widely used due to its simplicity implementation. Particularly in LQR method, the values of Q and R matrices are prespecified to determine optimal feedback control gain via Riccati equation [8].

On another aspect, an acceptable system performance with reduced vibration that accounts for system changes can be achieved by developing a hybrid control scheme that caters for rigid body motion and vibration of the system independently. This can be realized by utilizing control strategies consisting of either non-collocated with collocated feedback controllers or feed-forward with feedback controllers. In both cases, the former can be used for vibration suppression and the latter for input tracking of a flexible manipulator. A hybrid collocated and non-collocated controller has widely been proposed for control of a flexible structure [8, 9, 10]. The works have shown that the control structure gives a satisfactory system response with significant vibration reduction as compared to a response with a collocated controller. A feedback control with a feed-forward control to regulate the position of a flexible structure has previously been proposed [11, 12]. A control law partitioning scheme which uses end-point sensing device has also been reported [13]. The scheme uses end-point position signal in an outer loop controller to control the flexible modes, whereas the inner loop controls the rigid body motion independent of the flexible dynamics of the manipulator.

This paper presents investigation into the development of control schemes for trajectory tracking of tip angular position and vibration control of flexible joint manipulator. Control strategies based on collocated PD-type FLC with non-collocated fuzzy and the combination of collocated PD-type FLC with input shaping are investigated. For non-collocated control, a deflection angle feedback through a fuzzy logic control configuration whereas input shaping is utilised as a feed-forward scheme for reducing a deflection effect. A simulation environment is developed within Simulink and Matlab for evaluation of performance of the control schemes. The rest of the paper is structured as follows: Section 2 provides a brief description of the single-link flexible joint manipulator system considered in this study. Section 3 describes the modelling of the system derived using Euler-Lagrange formulation. The composite collocated PD-type FLC with fuzzy logic control and input shaping scheme are described in Section 4. Simulation results and comparative assessment are presented in Section 5 and the paper is concluded in Section 6.

2. THE FLEXIBLE JOINT MANIPULATOR SYSTEM

The flexible joint manipulator system considered in this work is shown in Fig. 1, where θ is the tip angular position and α is the deflection angle of the flexible joint. The base of the flexible joint manipulator which determines the tip angular position of the flexible link is driven by servomotor, while the flexible link will response based on base movement. The deflection of link will be determined by the flexibility of the spring as their intrinsic physical characteristics.

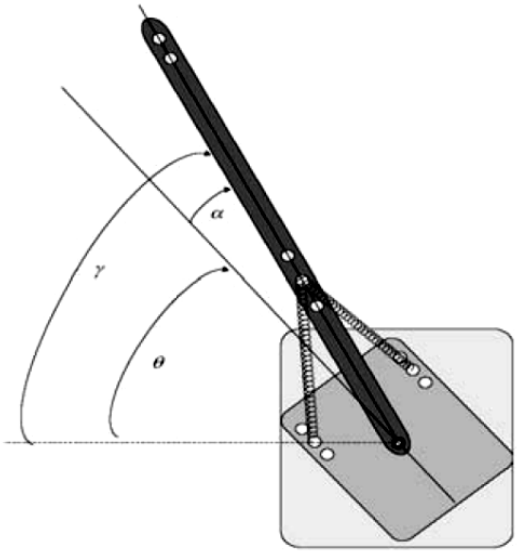


Fig. 1. Description of the flexible joint manipulator system

3. MODELLING OF THE FLEXIBLE JOINT MANIPULATOR

This section provides a brief description on the modelling of the flexible joint manipulator system, as a basis of a simulation environment for development and assessment of the hybrid Fuzzy Logic control techniques. The Euler-Lagrange formulation is considered in characterizing the dynamic behaviour of the system.

The linear model of the uncontrolled system can be represented in a state-space form [15] as shown in equation (1), that is

$$\begin{aligned} \dot{x} &= Ax + Bu \\ y &= Cx \end{aligned} \tag{1}$$

with the vector $x = \begin{bmatrix} \theta & \alpha & \dot{\theta} & \dot{\alpha} \end{bmatrix}^T$ and the matrices A, B and C are given by

$$A = \begin{bmatrix} 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \\ 0 & \dfrac{K_{stiff}}{J_{eq}} & \dfrac{-\eta_m \eta_g K_t K_m K_g^2 + B_{eq} R_m}{J_{eq} R_m} & 0 \\ 0 & \dfrac{-K_{stiff}(J_{eq} + J_{arm})}{J_{eq} J_{arm}} & \dfrac{\eta_m \eta_g K_t K_m K_g^2 + B_{eq} R_m}{J_{eq} R_m} & 0 \end{bmatrix}$$

$$B = \begin{bmatrix} 0 & 0 & \dfrac{\eta_m \eta_g K_t K_g}{J_{eq} R_m} & \dfrac{-\eta_m \eta_g K_t K_g}{J_{eq} R_m} \end{bmatrix}, \quad C = \begin{bmatrix} 1 & 0 & 0 & 0 \end{bmatrix} \tag{2}$$

In equation (1), the input u is the input voltage of the servomotor, V_m, which determines the flexible joint manipulator base movement. In this study, the values of the parameters are defined in Table 1.

Table 1

System parameters

Symbol	Quantity	Value
R_m	Armature Resistance (Ohm)	2.6
K_m	Motor Back-EMF Constant (V·s/rad)	0.00767
K_t	Motor Torque Constant (N·m/A)	0.00767
J_{link}	Total Arm Inertia (kg·m^2)	0.0035
J_{eq}	Equivalent Inertia (kg·m^2)	0.0026
K_g	High Gear Ratio	14:5
K_{stiff}	Joint Stiffness	1.2485
B_{eq}	Equivalent Viscous Damping (N·m.s/rad)	0.004
η_g	Gearbox Efficiency	0.9
η_m	Motor Efficiency	0.69

4. CONTROL ALGORITHM

In this section, control schemes for rigid body motion control and vibration suppression of a flexible joint manipulator are proposed. Initially, a collocated PD-type FLC controller is designed. Then a non-collocated fuzzy logic control and input shaping scheme are incorporated in the closed-loop system for control of vibration of the system.

a) PD-type fuzzy logic controller (PD-FLC)

A PD-type fuzzy logic controller (FLC) utilizing tip angular position error and derivative of tip angular position error is developed to control the rigid body motion of the system. The hybrid fuzzy control system proposed in this work is shown in Fig. 2, where $r(t).\theta(t)$ and $\alpha(t)$ are the desired angle, tip angular position and deflection angle of the flexible joint manipulator, whereas k_1, k_2 and k_3 are scaling factors for two inputs and one output of the fuzzy logic controller used with the normalized universe of discourse for the fuzzy membership functions.

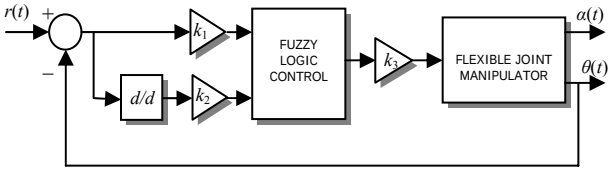


Fig. 2. PD-type fuzzy logic control structure

For PD-type FLC, triangular membership functions are chosen for tip angle error, tip angle error rate, and input voltage with 50% overlap. Normalized universes of discourse are used for both tip angle error and its error rate and input voltage. Scaling factors k_1 and k_2 are chosen in such a way as to convert the two inputs within the universe of discourse and activate the rule base effectively, whereas k_3 is selected such that it activates the system to generate the desired output. Initially all these scaling factors are chosen based on trial and error. To construct a rule base, the tip angle error, tip angle error rate, and input voltage are partitioned into five primary fuzzy sets as:

– tip angle error E = {NM NS ZE PS PM},

– tip angle error rate V = {NM NS ZE PS PM},

– voltage U = {NM NS ZE PS PM},

where E, V, and U are the universes of discourse for tip angle error, tip angle error rate and input voltage, respectively. The nth rule of the rule base

for the FLC, with angle error and angle error rate as inputs, is given by

R_n: IF(e is E_i) AND ($\dot{e}$ is V_j) THEN (u is U_k),

where R_n, n = 1, 2,…N_{max}, is the nth fuzzy rule, E_i, V_j, and U_k, for i, j, k = 1, 2,…,5, are the primary fuzzy sets.

A PD-type FLC was designed with 11 rules as a closed loop component of the control strategy for maintaining the angular position of flexible joint manipulator. The rule base was extracted based on underdamped system response and is shown in Table 2. The three scaling factors, k_1, k_2 and k_3 were chosen heuristically to achieve a satisfactory set of time domain parameters. These values were recorded as k_1 = 0.552, k_2 = 0.073 and k_3 = –985.

Table 2

Linguistic rules of the PD-type fuzzy logic controller

No.	Rules
1.	If (e is NM) and ($\dot{e}$ is ZE) then (u is PM)
2.	If (e is NS) and ($\dot{e}$ is ZE) then (u is PS)
3.	If (e is NS) and ($\dot{e}$ is PS) then (u is ZE)
4.	If (e is ZE) and ($\dot{e}$ is NM) then (u is PM)
5.	If (e is ZE) and ($\dot{e}$ is NS) then (u is PS)
6.	If (e is ZE) and ($\dot{e}$ is ZE) then (u is ZE)
7.	If (e is ZE) and ($\dot{e}$ is PS) then (u is NS)
8.	If (e is ZE) and ($\dot{e}$ is PM) then (u is NM)
9.	If (e is PS) and ($\dot{e}$ is NS) then (u is ZE)
10.	If (e is PS) and ($\dot{e}$ is ZE) then (u is NS)
11.	If (e is PM) and ($\dot{e}$ is ZE) then (u is NM)

b). PD-type fuzzy logic with non-collocated fuzzy logic controller (PD-FLC-FLC)

A combination of PD-type fuzzy logic and non-collocated fuzzy logic control scheme for control of tip angular position and vibration suppression of the system respectively is presented in this section. The use of a non-collocated control system, where the deflection angle of the flexible joint manipulator is controlled by measuring its angle, can be applied to improve the overall performance, as more reliable output measurement is obtained. The control structure comprises two feedback loops: (1) The hub angle as input to PD-type FLC for tip angular position control. (2) The deflection angle as input to a separate non-collocated control law for vibration control. These two loops are then summed together to give a torque input to the system. A block diagram of the composite fuzzy logic control scheme is shown in Fig. 3.

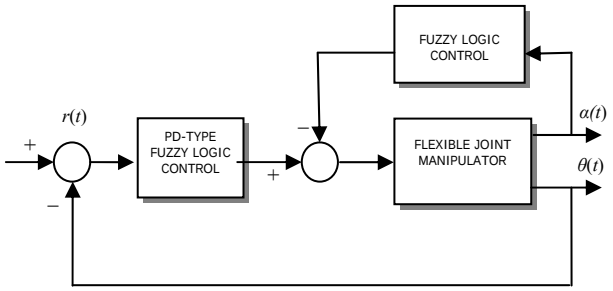


Fig. 3. PD-type FLC with non-collocated fuzzy logic control structure

For tip angular position control, the PD-type FLC strategy developed in the previous section is adopted whereas for the vibration control loop, the deflection angle feedback through a non-collocated fuzzy logic control scheme is utilized. In designing the non-collocated fuzzy logic control, a basic triangle and trapezoidal forms are chosen for input and output membership functions. Fig. 4 shows the membership functions of the fuzzy logic controller for vibration control. It consists of Negative Big (NB), Negative Small (NS), Zero (Z), Positive Small (PS) and Positive Big (PB) as shown in the diagram. The universes of discourses of deflection angle, deflection angle rate and input voltage are from 1.2 to –1.2 rad, –0.015 to 0.015 rad/s and –447 to 447 V, respectively.

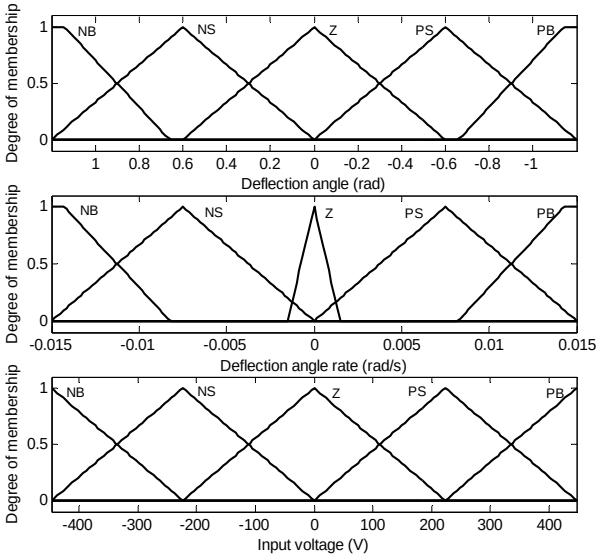


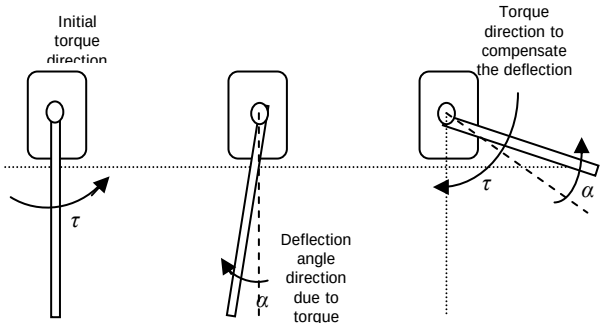
Fig. 4. Membership functions of inputs and output signals

Table 3 lists the generated linguistic rules for vibration control. The rules are designed based on

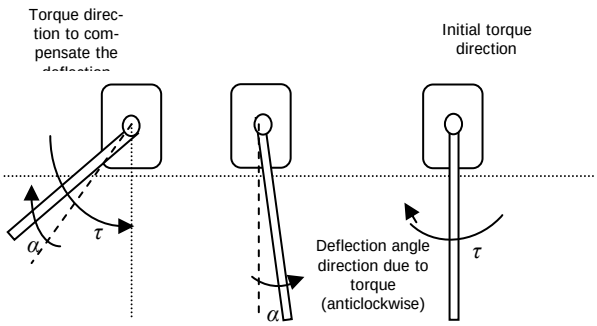
the condition of the deflection angle and the deflection angle rate as illustrated in Fig. 5. Consider the joint of the manipulator rotates to anti-clockwise direction and the link deflects on clockwise direction. As illustrated in Fig. 5(a), at this condition intuitively the torque should be applied to clockwise direction in order to compensate the deflection. In this case the relation between input voltage and torque per inertia is shown in equation (3),

$$\tau = \frac{V_m \eta_m \eta_g K_t K_g}{R_m} \tag{3}$$

Meanwhile, if the joint rotates to clockwise direction as shown in Fig. 5(b) and the link deflects to anti-clockwise direction; the torque should be imposed to anti-clockwise direction to suppress the deflection motion. In the case there is no deflection, no torque should be applied. Furthermore, the proposed fuzzy logic control adopts well-known Mamdani min-max inference and centre of area (COA) methods.



a) Direction of torque to reduce deflection angle when link moves anti-clockwise



b) Direction of torque to reduce deflection angle when link moves clockwise

Fig. 5. Rules generation based on the motion condition

Table 3

Fuzzy rules for vibration control

Deflection angle rate / Deflection angle	$\dot{\alpha}$ PB	PS	Z	NS	NB
α	PB	PB	PB	PB	NB	NB
	PS	PB	PS	PS	NS	NB
	Z	PB	PS	Z	NS	NB
	NS	PB	PS	NS	NS	NB
	NB	PB	PB	NB	NB	NB

c) PD-type fuzzy logic with input shaping (PD-FLC-IS)

A control structure for control of rigid body motion and deflection angle reduction of the flexible joint manipulator based on PD-type FLC and input shaping scheme is proposed in this section. The positive input shapers are proposed and designed based on the properties of the system. In this study, the input shaping control scheme is developed using a Zero-Vibration-Derivative-Derivative (ZVDD) input shaping technique [12]. Previous experimental study with a flexible manipulator has shown that significant vibration reduction and robustness is achieved using a ZVDD technique [15]. A block diagram of the PD-type FLC with input shaping control technique is shown in Fig. 6.

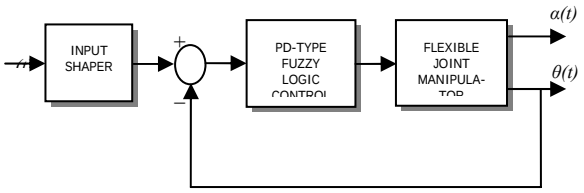


Fig. 6. PD-type FLC with input shaping control structure

The input shaping method involves convolving a desired command with a sequence of impulses known as input shaper. The design objectives are to determine the amplitude and time location of the impulses based on the natural frequencies and damping ratios of the system. The positive input shapers have been used in most input shaping schemes. The requirement of positive amplitude for the impulses is to avoid the problem of large amplitude impulses. In this case, each individual impulse must be less than one to satisfy the unity magnitude constraint. In addition, the robustness of the input shaper to errors in natural frequencies of

the system can be increased by solving the derivatives of the system vibration equation. This yields a positive ZVDD shaper with parameter as

$$t_1 = 0, \quad t_2 = \frac{\pi}{\omega_d}, \quad t_3 = \frac{2\pi}{\omega_d}, \quad t_4 = \frac{3\pi}{\omega_d}$$

$$A_1 = \frac{1}{1+3H+3H^2+H^3}, \quad A_2 = \frac{3H}{1+3H+3H^2+H^3},$$

$$A_3 = \frac{3H^2}{1+3H+3H^2+H^3}, \quad A_4 = \frac{H^3}{1+3H+3H^2+H^3}, \tag{4}$$

where

$$H = e^{-\zeta\pi/\sqrt{1-\zeta^2}}, \quad \omega_d = \omega_n\sqrt{1-\zeta^2},$$

ω_n and ζ representing the natural frequency and damping ratio, respectively. For the impulses, t_j and A_j are the time location and amplitude of impulse *j,* respectively.

5. IMPLEMENTATION AND RESULTS

In this section, the proposed control schemes are implemented and tested within the simulation environment of the flexible joint manipulator and the corresponding results are presented. The manipulator is required to follow a trajectory of 50º. System responses namely the tip angular position and deflection angle are observed. To investigate the vibration of the system in the frequency domain, power spectral density (PSD) of the deflection angle response is obtained. The performances of the control schemes are assessed in terms of vibration suppression, trajectory tracking and time response specifications. Finally, a comparative assessment of the performance of the control schemes is presented and discussed.

Figs. 7–9 show the responses of the flexible joint manipulator to the reference input trajectory using PD-FLC in time-domain and frequency domain (PSD). These results were considered as the system response under rigid body motion control and will be used to evaluate the performance of the non-collocated fuzzy logic control and input shaping scheme. The steady-state tip angular trajectory of 50º for the flexible joint manipulator was achieved within the rise and settling times and overshoot of 0.222 s, 0.565 s and 1.78 %, respectively.

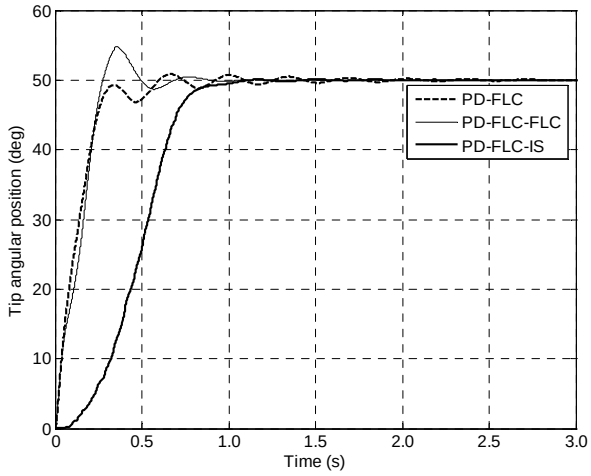


Fig. 7. Tip angular position response

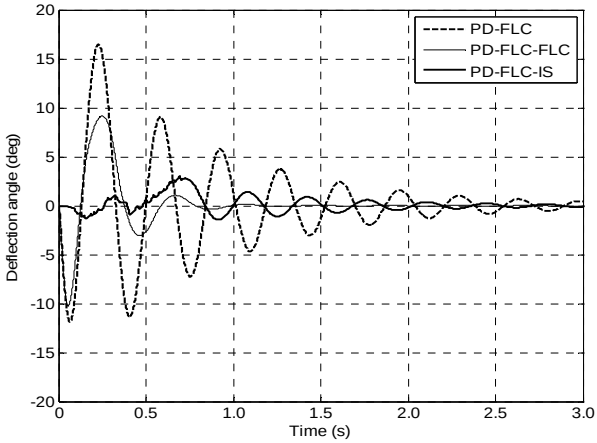


Fig. 8. Deflection angle response

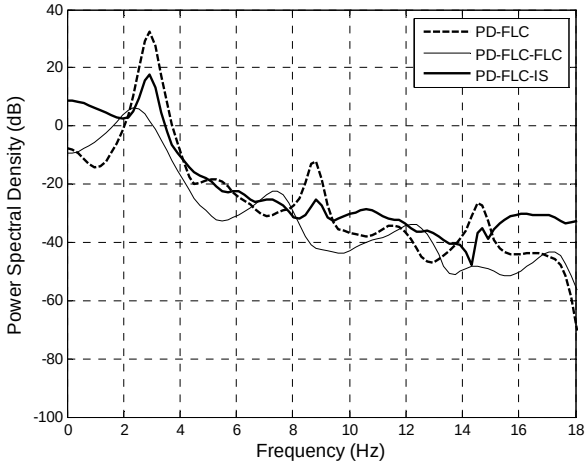


Fig. 9. PSD of deflection angle

It is noted that the manipulator reaches the required position within 1 s, with little overshoot. However, a noticeable amount of vibration occurs during movement of the manipulator. It is noted from the deflection angle response that the vibra-

tion of the system settles within 3 s with a maximum residual of ± 15º. Moreover, from the PSD of the deflection angle response the vibrations at the flexible joint are dominated by the first three vibration modes, which are obtained as 2.94 Hz, 8.83 Hz and 14.52 Hz with magnitude of 32.38 dB, –12.08 dB and –26.52 dB, respectively.

The tip angular position, deflection angle and power spectral density responses of the flexible joint manipulator using PD-FLC-FLC and PD-FLC-IS are shown in Figs. 7–9, respectively. It is noted that the proposed control schemes are capable of reducing the system vibration while maintaining the trajectory tracking performance of the manipulator. Similar tip angular position, deflection angle and power spectral density of deflection angle responses were observed as compared to the PD-FLC. With PD-FLC-FLC, the steady-state tip angular trajectory of 50º for the flexible joint manipulator was achieved within the rise and settling times and overshoot of 0.215 s, 0.613 s and 9.68 %, respectively. While with PD-FLC-IS the manipulator reached the rise, settling times and overshoot of 0.469 s, 0.857 s and 0.16 %, respectively. It is noted that, the settling time of PD-FLC-FLC is much faster as compared to the case of PD-FLC-IS. However, the percentage overshoot of PD-FLC-IS is much lower than the case of PD-FLC-FLC. Besides, the results also demonstrate a significant amount of deflection angle reduction at the tip angle of the manipulator with both controllers. The vibration of the system using PD-FLC-FLC settles within 1 s which is much faster as compared to PD-FLC-IS. However, in terms of maximum residual of deflection angle, the PD-FLC-IS and PD-FLC-FLC produces a four-fold and two-fold improvement respectively as compared to PD-FLC scheme. Moreover, from the PSD of the deflection angle response, the magnitudes of vibrations using PD-FLC-FLC and PD-FLC-IS were reduced to 1.87, –41.95, –48.25 dB and 17.59, –25.28, –36.69 dB, respectively, for the first three modes of vibration.

Table 4 summarizes the magnitude of vibration of deflection angle and specifications of tip angular position response for both control schemes. It is noted that high performance in the reduction of vibration of the system is achieved using PD-FLC-FLC as compared to PD-FLC-IS. This is observed and compared to the PD-FLC at the first three modes of vibration. In addition, as demonstrated in the tip angular trajectory response, a slightly faster response with higher overshoot is obtained using PD-FLC-FLC as compared to the PD-FLC-IS. Comparisons of the specifications of the tip angular trajectory responses are summarized in Table 4. Besides, as demonstrated in the tip angular trajectory response with PD-FLC-FLC, the minimum phase behaviour of the manipulator is unaffected. Nevertheless, the implementation of PD-FLC-IS is much easier as compared to PD-FLC-FLC as a large amount of design effort is required in order to determine the best range of membership functions parameters.

Table 4

Magnitude of vibration and specifications of tip angular position

Controller		PD–FLC	PD–FLC–FLC	PF–FLC–IS
Magnitude of vibration (dB)	Mode 1	32.38	1.87	17.59
	Mode 2	–12.08	–41.95	–25.28
	Mode 3	–26.52	–48.25	–36.69
Specifications of tip angular position response	Settling time (s)	0.565	0.613	0.857
	Rise time (s)	0.222	0.215	0.469
	Overshoot (%)	1.78	9.68	0.16

6. CONCLUSIONS

The development of techniques for trajectory tracking and vibration suppression of a flexible joint manipulator has been presented. The control schemes have been developed based on collocated PD-type FLC with non-collocated fuzzy logic control and PD-type FLC with input shaping scheme. The proposed control schemes have been implemented and tested within simulation environment of a flexible joint manipulator. The performances of the control schemes have been evaluated in terms of input tracking capability and vibration suppression at the resonance mode of the manipulator. Acceptable performance in input tracking and vibration control has been achieved with proposed control strategies. A comparative assessment of the control schemes has shown that the PD-FLC-FLC performs better than the PD-FLC-IS in respect of deflection angle reduction of the elastic joint. Moreover, in term of speed of responses, PD-FLC-FLC results in a faster settling time response with high overshoot as compared to PD-FLC-IS. The work thus developed and reported in this paper forms the basis of design and development of hybrid control schemes for input tracking and vibra-

tion suppression of multi-link flexible manipulator systems and can be extended to and adopted in practical applications.

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Original scientific paper

STRUCTURAL AND CONTACT ANALYSIS OF DISC BRAKE ASSEMBLY DURING SINGLE STOP BRAKING EVENT

Ali Belhocine[1], Abd Rahim Abu Bakar[2], Mostefa Bouchetara[3]

[1,3]*Institute of Mechanical Engineering, Faculty of Mechanical Engineering, University of Sciences and the Technology of Oran, L.P 1505 El - Mnaouer, USTO 31000 Oran (Algeria)*
[2]*Department of Automotive Engineering, Universiti Teknologi Malaysia, 81310 UTM Skudai (Malaysia).*
al.belhocine@yahoo.fr // arahim@fkm.utm.my

A b s t r a c t: An automobile disc brake system is used to perform three basic functions, i.e. to reduce speed of a vehicle, to maintain its speed when travelling downhill and to completely stop the vehicle. During these braking events, the disc brake may suffer of structural and wear issues. It is quite sometimes that the disc brake components fail structurally and/or having severe wear on the pad. Thus, this paper aims to examine stress concentration, structural deformation and contact pressure of brake disc and pads during single braking stop event by employing commercial finite element software, ANSYS. The paper also highlights the effects of using a fixed calliper, different friction coefficients and different speeds of the disc on the stress concentration, structural deformation and contact pressure of brake disc and pads, respectively.

Key words: disc brake; Von Mises stress; structural deformation; contact pressure; finite element

СТРУКТУРНА И КОНТАКТНА АНАЛИЗА НА СКЛОП НА КОЧНИЦИ СО ДИСКОВИ ЗА ВРЕМЕ НА ЕДИНИЧНО СОПИРАЊЕ

А п с т р а к т: Систем за кочење кај автомобилите има 3 основни функции: да ја намали брзината на возилото, да ја одржи брзината кога возилото се движи по удолница и целосно да го запре возилото. За време на кочење дисковите можат да трпат структурни проблеми или проблеми од замор на материјалот. Често се случува компоненти на системот за кочење да откажат поради промена на структурата или површината на материјалот. Овој труд е посветен на истражувања на концентрација на напон, деформации и притисок на допир на дисковите за време на единично сопирање со употреба на комерцијален софтвер за метод на конечни елементи, AHCSC. Трудот исто така се фокусира на ефектот на користење фиксен носач на плочките, различни фрикциони коефициенти и различни брзини на дискот врз концентрацијата на напони, деформацијата и притисокот на допир на дисковите и плочките, соодветно.

Клучни зборови: диск за кочење; Von Mises-ов напон; деформација; притисок на допир; конечен елемент

1. INTRODUCTION

Passenger car disc brakes are safety-critical components whose performance depends strongly on the contact conditions at the pad-to-rotor interface. When the driver steps on the brake pedal, hydraulic fluid is pushed against the piston, which in turn forces the brake pads into contact with the rotor. The frictional forces at the sliding interfaces between the pads and the rotor retard the rotational movement of the rotor and the axle on which it is mounted [1]. The kinetic energy of the vehicle is transformed into heat that is mainly absorbed by the rotor and the brake pad.

The frictional heat generated on the interface of the disc and the pads can cause high tempera-

ture. Particularly, the temperature may exceed the critical value for a given material, which leads to undesirable effects, such as brake fade, local scoring, thermo elastic instability, premature wear, brake fluid vaporization, bearing failure, thermal cracks, and thermally excited vibration [2, 3]. Gao and Lin [2] stated that there was considerable evidence to show that the contact temperature is an integral factor reflecting the specific power friction influence of combined effect of load, speed, friction coefficient, and the thermo physical and durability properties of the materials of a frictional couple. Lee and Yeo [3] reported that uneven distribution of temperature at the surfaces of the disc and friction pads brings about thermal distortion, which is known as coning and found to be the main cause of judder and disc thickness variation (DTV). AbuBakar et al. [4] in their recent work found that temperature could also affect vibration level in a disc brake assembly. Valvano and Lee [5] simulated thermal analysis on a disc brake with a combination of computer-based thermal model and finite element-based techniques to provide a reliable method to calculate the temperature rise, thermal stress and distortion under a given brake schedule. Wolejsza et al. [6] performed analysis on the thermo-mechanical behavior of airplane carbon composite brakes using MSC/Marc finite element software which allows accurate simulation of the transient heat transfer phenomenon coupled to disc deformations caused by frictional sliding contact.

There are three types of mechanical stresses subjected by the disc brake. The first one is the traction force created by the centrifugal effect due to the rotational of the disc brake when the wheel is rotating and no braking force is applied to the disc. During braking operation, there are another two additional forces experienced by the disc brake. Firstly, compression force is created as the result of the force exerted by the brake pad pressing perpendicular onto the surface of the disc to slow it down. Secondly, the braking action due to the rubbing of the brake pad against the surface of the disc brake is translated into frictional or traction force on the disc surface which acts in the opposite direction of the disc rotation.

A disc brake of floating caliper design typically consists of pads, caliper, carrier, rotor (disc), piston, and guide pins. One of the major requirements of the caliper is to press the pads against the rotor and should ideally achieve as uniform interface pressure as possible. A uniform pressure between the pads and rotor leads to uniform pad wear and brake temperature, and more even friction coefficients [7]. Unevenness of the pressure distribution could cause uneven wear and shorter life of pads. It has also speculated that they may promote disc brake squeal. The interface pressure distributions have been investigated by a number of people. Tirovic and Day [8] studied the influence of component geometry, material properties and contact characteristics on the interface pressure distribution. Belhocine and Bouchetara [9] recently studied the interface pressure distributions of the inner pad under the influence of the thermomechanical coupling in the braking process. They used a simple and nonvalidated, three-dimensional model of the disc brake. Tamari et al. [10] presented a method of predicting disc brake pad contact pressure for certain operating condition by means of experimental and numerical method. They developed a quite detailed model and validated the model by fitting the numerical deformations of the disc brake components with experimental results. Hohmann et al. [11] also presented a method of contact analysis for the drum and disc brakes of simple three-dimensional models using ADINA software package. They showed a sticking and shifting contact area in their results. Like [8], validation of their model was not made. Ripin [12] developed a simple, validated three-dimensional finite element model of the pad, and applied rather simple piston and finger force onto the back plate interface in his analysis. He studied the contact pressure distribution at the disc/pad interface, where gap elements were used to represent contact effect.

In this paper, structural analysis is performed on a simple finite element (FE) model of a real disc brake assembly to obtain the contact pressure distributions on the friction pads and the Von Mises Stress in disc interface by utilizing the ANSYS 11.0 FE software. Sensitivity study on rotation of the disc, load pattern and coefficient of friction is also performed.

2. INITER ELEMENT ANALYSIS

In this work, a three dimensional CAD and FE model consists of a ventilated disc and two pads with single slot in the middle as illustrated in Fig. 1 and Fig. 2, respectively. The selected material of the disc is Gray cast iron FG 15 with high Carbon content and the brake pad has an isotropic elastic behavior whose mechanical characteristics of the two parts are presented in Table 1. The ma-

terials of the disc and the pads are homogeneous and their properties are invariable with the temperature.

Table 1

Mechanical properties of the disc and pad

Properties	Disc	Pad
Young modulus E (GPa)	138	1
Poisson's ratio ν	0.3	0.25
Density ρ (kg/m^3)	7250	1400
Coefficient of friction μ	0.2	0.2

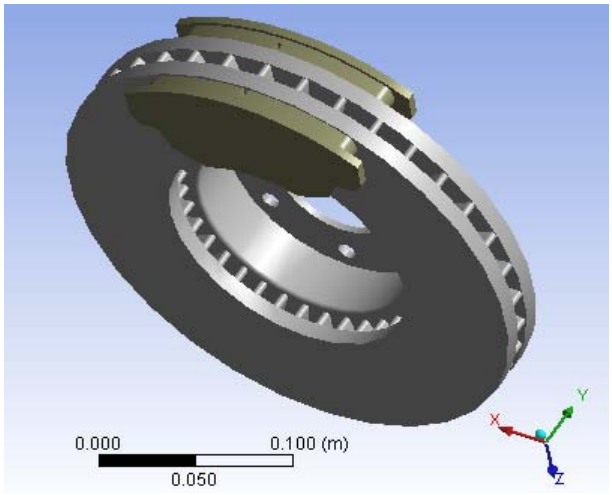


Fig. 1. CAD model of the disc and pads

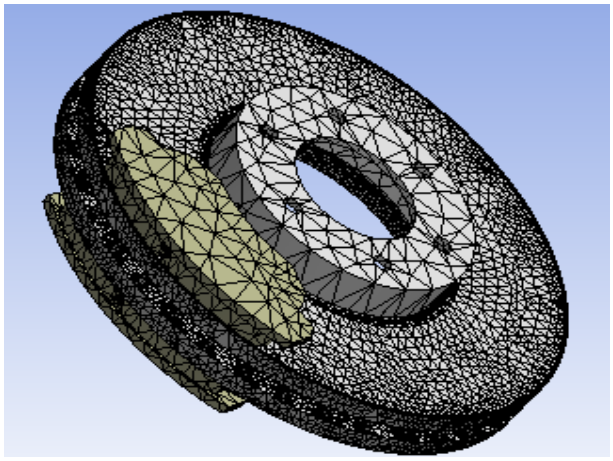
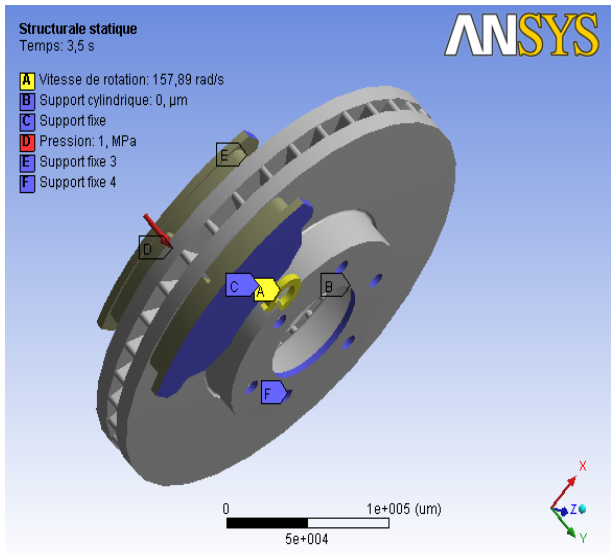
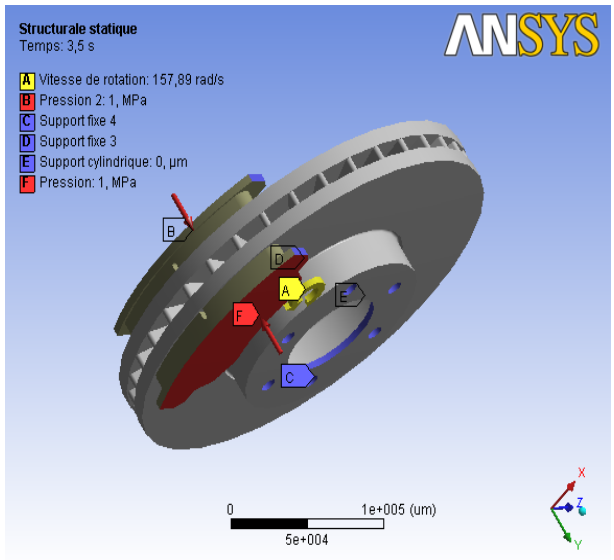


Fig. 2. FE model of the disc and pads

A commercial FE software, namely ANSYS 11 (3D) is fully utilised to simulate structural deformation and contact pressure distributions of the disc brake during single braking stop application. Boundary conditions are imposed on the models (disc-pad) as shown in Fig. 3a for applied pressure on one side of the pad and Fig. 3b for applied pressure on both sides of the pad. The disc is rigidly constrained at the bolt holes in all directions except in its rotational direction. Meanwhile, the pad is fixed at the abutment in all degrees of freedom except in the normal direction to allow the pads move up and down and in contact with the disc surface. In this study, it is assumed that 60% of the braking forces are supported by the front brakes (two rotors) [13]. By using vehicle data as given in Table 2 and Eqs. (1) – (3), braking force on the disc, rotational speed and brake pressure on the pad can be calculated, respectively.



a) One side



(b) Two sides

Fig. 3 Boundary conditions and loading imposed on the disc-pads

T a b l e 2

Vehicle data

Properties	Value
Mass of the vehicle, M (kg)	1385
Initial velocity – v_0 (m/s)	60
Time to stop t_{stop} (s)	45
Effective rotor radius – R_{rotor} (mm)	101
Radius of the wheel – R_{tire} (mm)	380
The coefficient of friction disc/pads μ	0.2
Surface of the pad A_c (mm^2)	5246

$$F_{\text{disc}} = \frac{(30\%)\cdot\frac{1}{2}Mv_0^2}{2\cdot\frac{R_{\text{rotor}}}{R_{\text{tire}}}\left(v_0\cdot t_{\text{stop}} - \frac{1}{2}\left\{\frac{v_0}{t_{\text{stop}}}\right\}t_{\text{stop}}^2\right)} = 1047.36 \text{ N} \tag{1}$$

The rotational speed of the disc is calculated as follows:

$$\omega = \frac{v_0}{R_{tire}} = 157.89 \text{ rad/ s}. \tag{2}$$

The external pressure between the disc and the pads is calculated by the force applied to the disc; for a flat track, the hydraulic pressure is, as referred to [14]:

$$P = \frac{F_{\text{disc}}}{A_c \cdot \mu} = 1 \text{ MPa}, \tag{3}$$

where A_c is the surface of the pad in contact with the disc and μ the coefficient of friction.

3. RESULTS AND DISCUSSION

3.1. *Von Mises stress distribution*

Figure 4 shows distributions of the equivalent Von Mises stress over braking period and it is shown that the highest stress occurs at the bolt holes at the time t = 0.25 s. This is due to the disc having experience in torsion and shear modes. This high stress concentration can cause a rupture to the bolt holes.

3.2. *Contact pressure distribution*

Figure 5 illustrates contact pressure distributions of the inner pad at different braking times. It shows that the contact pressure increases gradually and reaches its maximum value of $P_{\max}$ = 1.8 MPa at the end of braking period. It is believed that the rise in pressure on the contact surface can also cause a rise in the temperature of the disc and wear of the pads. At the leading side and inner radius of the pad, contact pressure is seen to be higher compared to the other regions. This is due to this area is mostly in contact with the disc surface. Fig. 7 shows the evolution of contact pressures along angular positions of the pad. The maximum value of the contact pressure is located at the leading edge and at the level of the lower edge of the pad. Contact pressure distributions of the outer pad are depicted in Fig. 6. It shows that the maximum contact pressure is predicted in the middle of the pad with the value of 1.3 MPa. This is much lower than that obtained on the inner pad.

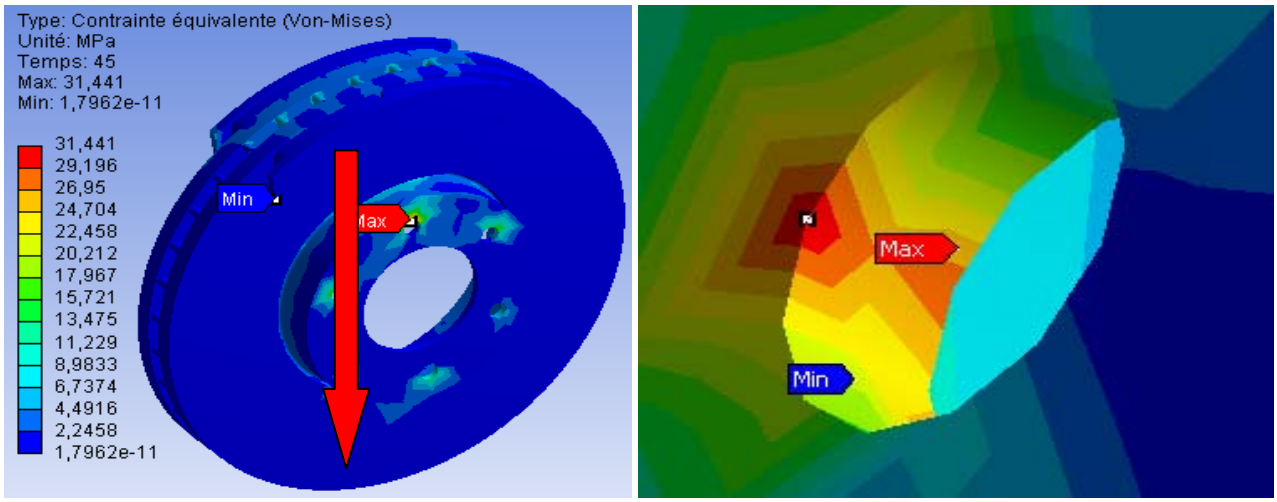
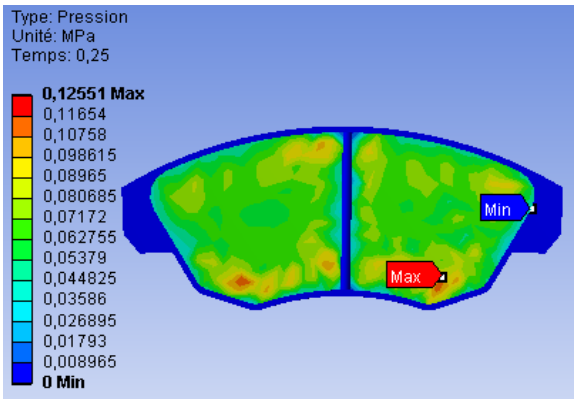
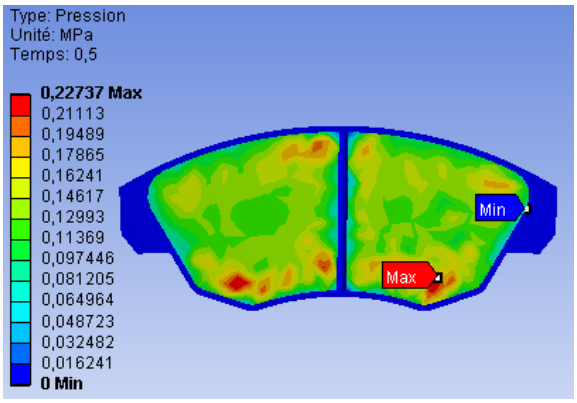


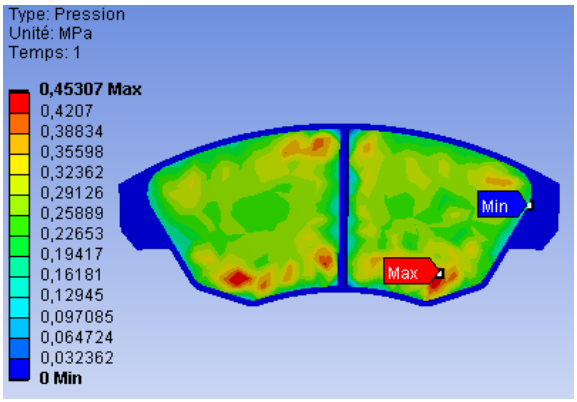
Fig. 4. Stress concentration at the bolt holes



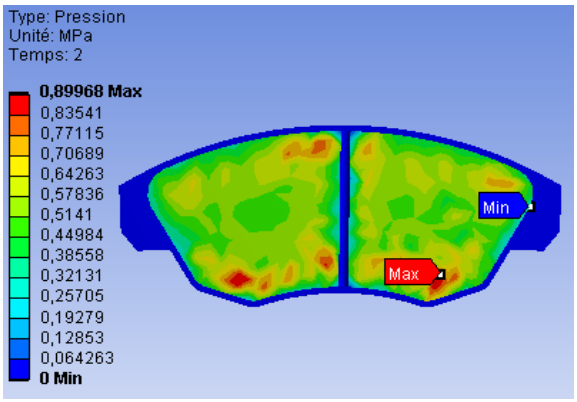
a) at time t = 0.25 s



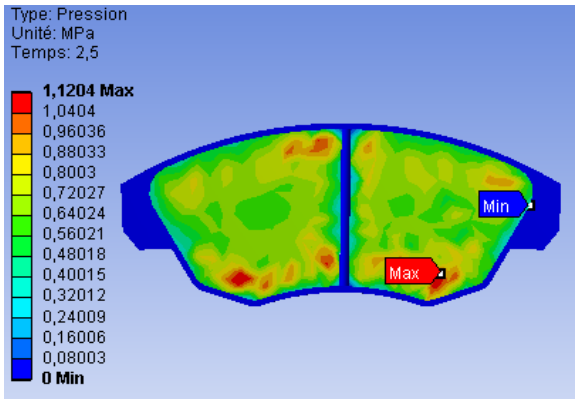
b) at time t = 0.5 s



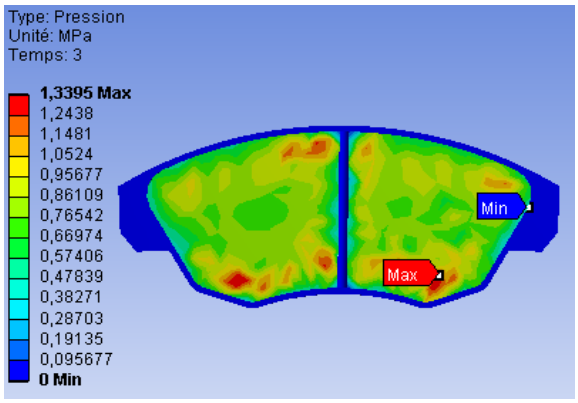
c) at time t = 1 s



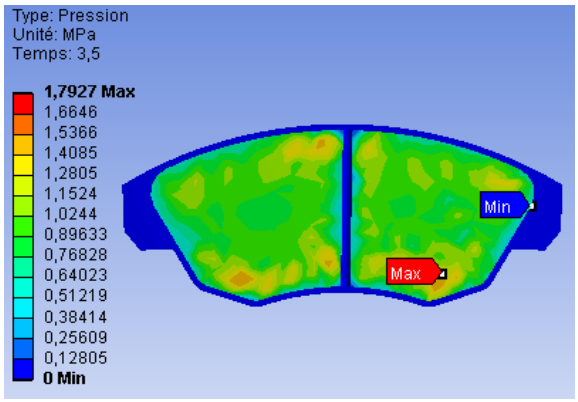
d) at time t =2 s



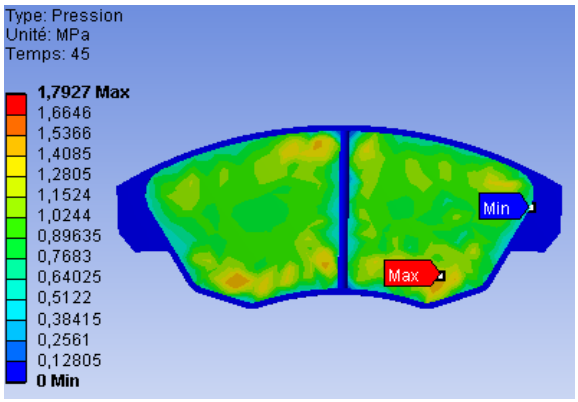
e) at time t = 2.5 s



f) at time t = 3 s

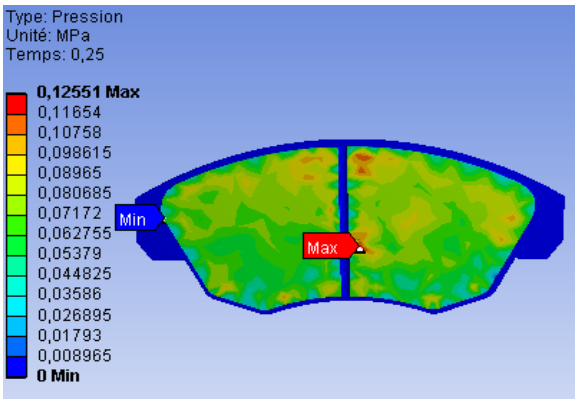


g) at time t = 3.5 s

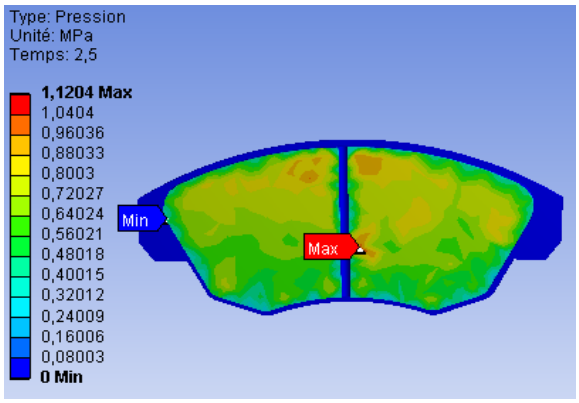


h) at time t = 45 s

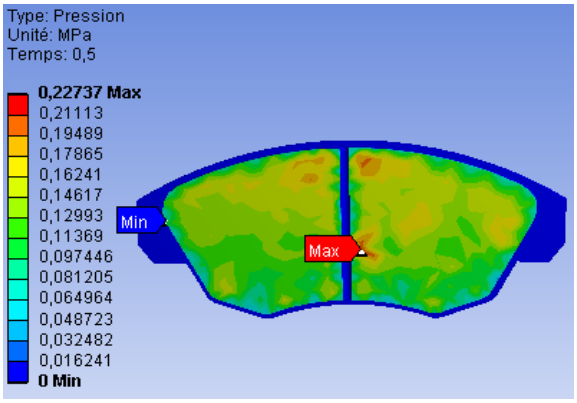
Fig. 5. Contact pressure distribution on the inner pad



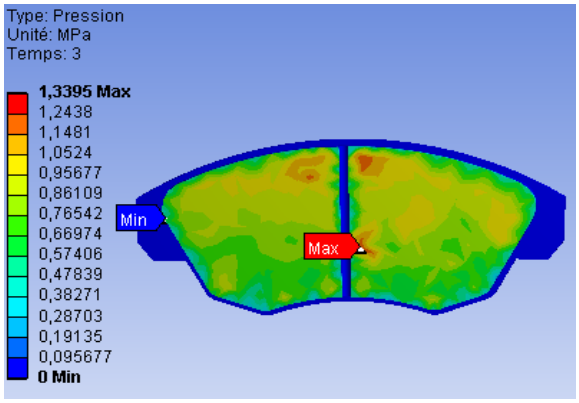
a) at time t = 0.25 s



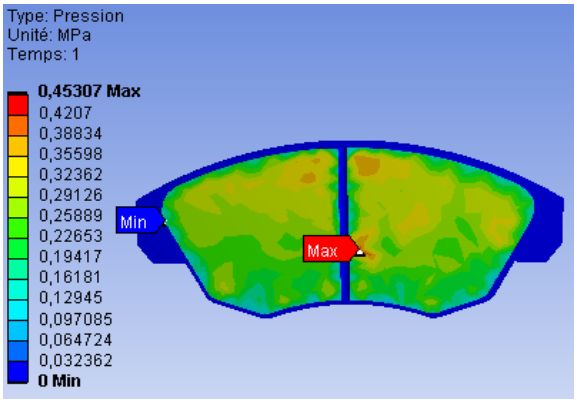
e): at time t = 2.5 s



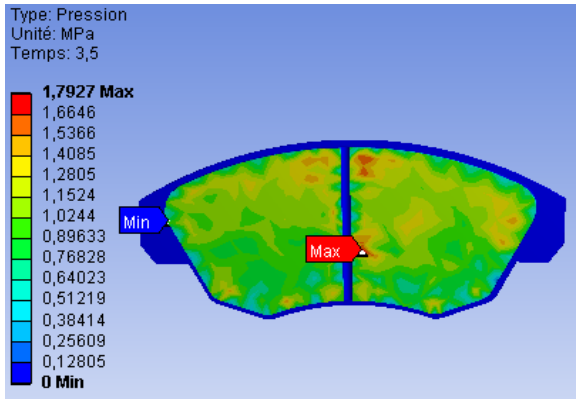
b) at time t = 0.5 s



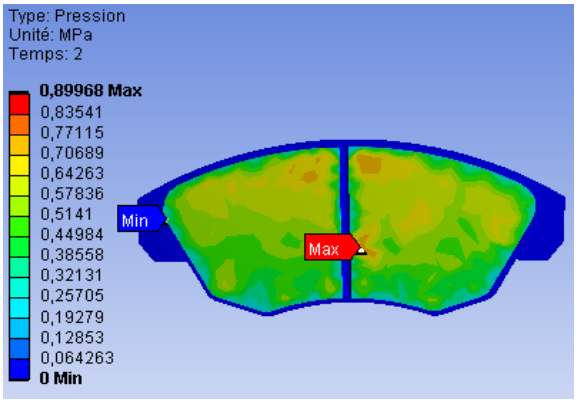
-f- : at time t= 3 s



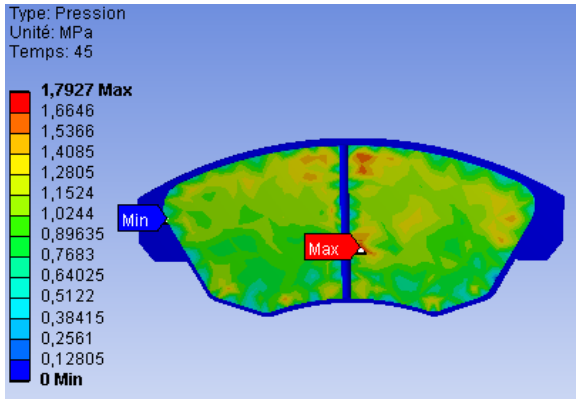
c) at time t = 1 s



g) at time t = 3.5 s



d): at time t =2 s



h): at time t = 45 s

Fig. 6. Contact pressure distribution on the outer pad

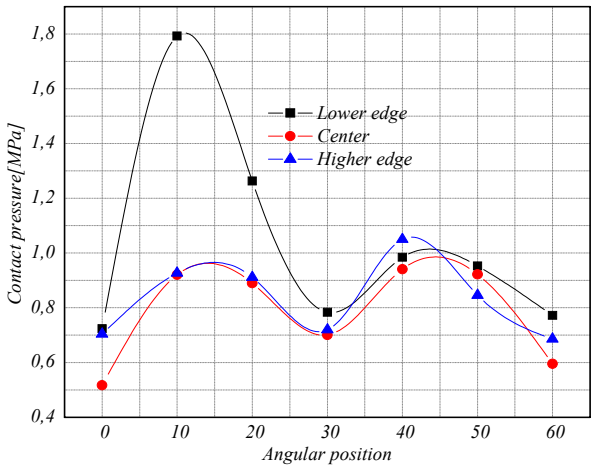


Fig. 7. Variation of contact pressures according to the angular position in the inner pad

3.3. Effect of a fixed caliper

For a comparative study, the effect of a fixed caliper (disc with double pressure) is also simulated where it maintains the same boundary conditions used in the case of a single-piston caliper. Fig. 8.shows the levels of equivalent Von Mises stresses in a section of a disc brake at the end of braking period. Unlike the case of the disc with a single-piston caliper, it is noted that the highest stress appears at the outer side of the fins with the value of 8.3 MPa. This is lower than the stress predicted at the bolt holes with the value of 31.4 MPa for single-piston caliper. It is also found that the stress is well distributed to the disc interface compared with stress predicted in Fig. 5.

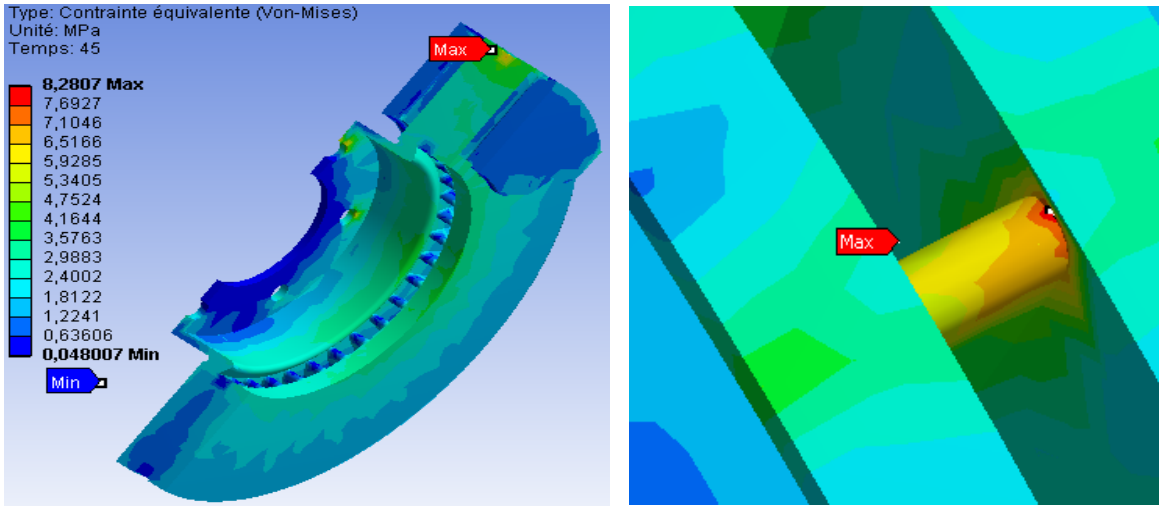


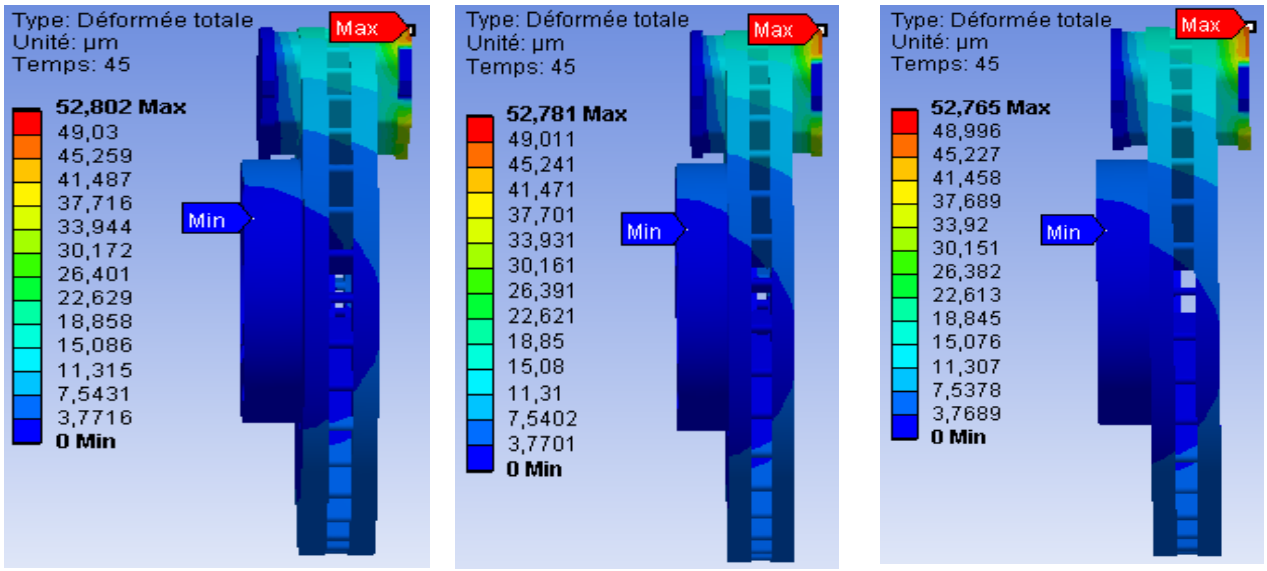
Fig. 8. Von Mises stresses

3.4. Effect of friction coefficient

It is interesting to see deformation behavior of the disc and the pads with respect to variation of friction coefficient from 0.25 to 0.35. Fig. 9. shows the different configurations of the total deformation of the model in the final stage of braking. It is clearly seen that the total deformation is slightly decreased with the increase of friction coefficient. Indeed, the high mechanical advantage of hydraulic and mechanical disc brakes allows a small lever input force at the handlebar to be converted into a large clamp force at the wheel. This large clamp force pinches the rotor with friction material pads and generates brake power. The higher the coefficient of friction for the pad, the more brake power will be generated coefficient of friction can vary depending on the type of material used for the brake rotor. If the value of the coefficient of friction is increased, the disc is slowed down by friction forces which are opposed to its movement, and the maximum deformation that it undergoes is less significant.

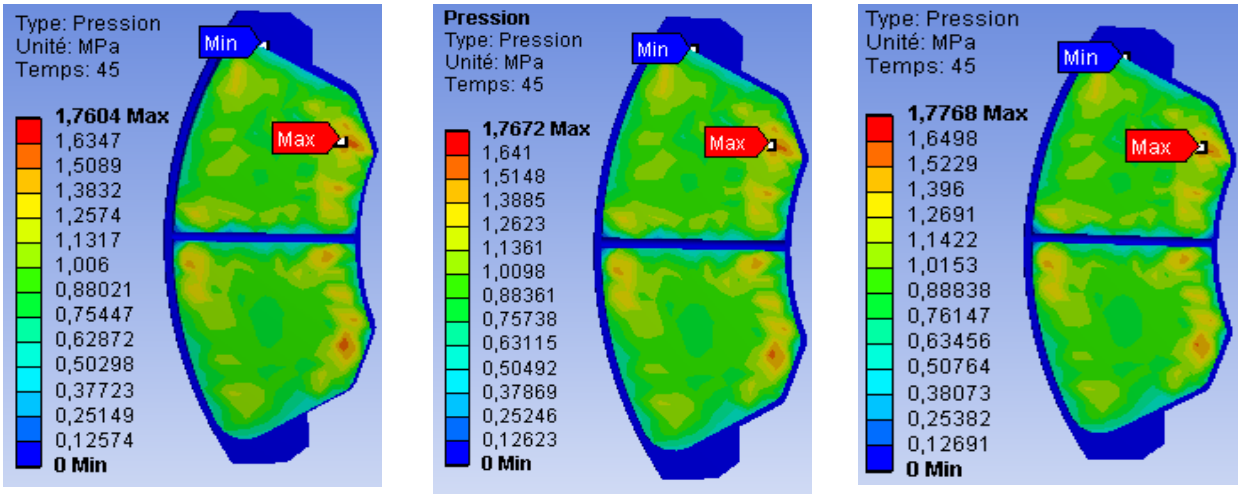
3.5. Effect of disc speed

Fig. 10 shows prediction of contact pressure distributions at three different speeds of the disc. It is found that contact pressure distribution is almost identical in all three cases and its value increases with the increase of the angular velocity of the disc. This was also confirmed by Abu Bakar et al. [15]. It is believed that this increase can create the wear of the pads as they can leave deposits on the disc, giving rise to what is called "the third body." It is noted that the maximum contact pressure is produced on the pad at the leading edge.



a) $\mu =$ 0.25 b) $\mu =$ 0.30 c) $\mu =$ 0.35

Fig. 9. Total deformation at the end of braking period



a) $\omega =$ 60 rad/s b) $\omega =$ 90 rad/s c) $\omega =$ 60 rad/s

Fig. 10. Contact pressure distributions

4. CONCLUSION

This paper presents structural and contact analysis of a reduced brake model without considering thermal effects. The analysis is performed using commercial FE software package, ANSYS, where the FE model only consists of a disc and two pads. From the single stop braking simulation it is found that:

- the bolt holes and outer side of the fins could first damage due to high stress concentration for single and double piston case, respectively;
- contact pressure is predicted higher at the leading side compared to the trailing side and its value slightly increases with the increase of disc rotation speeds;
- there is no significant change in disc-pad deformation with respect to the variation of friction coefficient.

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Original scientific paper

USE OF NATURAL GAS AS A CONTRIBUTION TO REDUCING EMISSIONS

Dame Dimitrovski[1], Goran Dimeski[2]

[1] *"Ss. Cyril and Methodius" University in Skopje, Faculty of Mechanical Engineering, Karpoš II. bb, P.O. box 464, 1001 Skopje, Republic of Macedonia*
[2] *Toplifikacija Inženering AD, 1000 Skopje, Republic of Macedonia*
dame.dimitrovski@mf.edu.mk

A b s t r a c t: Air quality is one of the conditions that affect both humans health also extend to natural ecosystems, stratospheric ozone, biosphere, changing weather conditions and climate. Imbalance in the atmosphere, the appearance of the greenhouse effect, as well as damage the ozone layer is due to the release of large amounts of polluting substances, which give the effect of acidification and ruin the biosphere, soil and affect others. Pollutants emitted into the air from various sources, mix it, and transported on greater distances and affect on air quality. The polluting substances emitted and remain part of the troposphere that is one part of the air that people breathe, with negative effect on human health, especially respiratory. Given the rapid growth of the industry and the growing need for energy, it is necessary to consider the possibilities for the application of alternative fuels as a proposal to reduce emissions. This paper is considered part of the urban area and thus created a comparative analysis of the work of one plant (which is mainly supplying the area with heat energy), in terms of the type of fuel and related emissions. Also consider the possibility and benefits of the use of natural gas as an alternative fuel to meet the needs of households. Prepared analysis is presented also with the benefits of replacing the electrical and thermal energy (taken from the district heating system) with the use of natural gas as energy terms, and the financial and environmental.

Key words: pollutions; emissions; energy; natural gas

УПОТРЕБА НА ПРИРОДЕН ГАС КАКО ПРИДОНЕС ЗА НАМАЛУВАЊЕ НА ЕМИСИИТЕ

А п с т р а к т: Квалитетот на воздухот е еден од условите кои влијаат како на здравјето на луѓето така и на природните екосистеми, стратосферскиот озон, биосферата, промените на временските услови и климата. Нарушената рамнотежа во атмосферата, појавата на ефектот на стаклена градина, како и оштетувањето на озонската обвивка, се последици на испуштањето големи количини загадувачки супстанции, кои даваат ефект на закиселување и ја разрушуваат биосферата, дејствуваат врз почвата и др. Загадувачките супстанции, кои од различни извори се испуштаат во воздухот и се мешаат со него, се транспортираат на поголеми далечини и влијаат на квалитетот на воздухот. Притоа загадувачките супстанции кои се емитуваат и остануваат во делот на тропосферата, каде што спаѓа и делот на воздухот што го дишат луѓето, влијаат негативно врз здравјето на луѓето, особено врз респираторните органи. Имајќи ги предвид брзиот развој на индустријата и зголемената потреба од енергија, неопходно е да се разгледаат можностите за примена на алтернативни горива како решение за намалување на емисиите. Во трудов е разгледуван дел од градското подрачје и е направена споредбена анализа на работа на една топлана (која во поголема мера го снабдува подрачјето со топлинска енергија) во однос на типот на горивата и соодветните емисии. Исто така се разгледува можноста и придобивките од примената на природниот гас како алтернативно гориво за задоволување на потребите на домаќинствата. Направена е анализа и посочен е бенефитот од замената на електричната и топлинската енергија (преземена од системот за далечинско греење) со природниот гас како од енергетски така и од финансиски и еколошки аспект.

Клучни зборови: загадувачки супстанции; емисии; енергија; природен гас

1. INTRODUCTION

Due to the increasing development of the industry and the growing number of people on Earth it causes properly increases the need for energy. In order to meet the needs of energy there is intensive depleting reserves of fossil fuels, and increasing the use of nuclear fuel and hydropower. Consider-

ing the fact that fossil fuels are non-renewable sources of energy, and also if the trend of their utilization is not reduced, then simultaneously with their use we are consciously violate the principle of sustainable development.

The need to protect the environment and reduce greenhouse gas emissions, also Macedonian import dependency on energy, and the need to ensure greater diversity and therefore security of energy supply, inevitably requires the adoption of measures and enforcement actions for increasing energy efficiency in final consumption.

Significant impact on air quality in urban areas have activities of human life or the so-called anthropogenic sources such as industrial processes, energy installations for power generation, heating in buildings (residential, administrative and commercial facilities), transportation [5] (road, air, ship), agriculture, waste and more.

Of particular importance is the availability of data on the origins, prevalence and impact of polluting substances present in the air in order to take measures for their reduction. It is often accepted approach to act locally in order to improve air quality globally. Reducing pollution from traffic, and the use of alternative energy sources, renewable sources, bio fuels and natural gas are the primary processes to improve air quality.

2. PARTITION TYPES OF POLLUTANTS

Pollutants can generally be divided into **gas, vapor, solid particles** and lately more often mentioned **scents**. Furthermore, in terms of size suspended particles are divided into: dust, smoke, fumes and aerosols.

Tables 1 and 2 show pollutants and upper limits of pollutants.

Gaseous pollutants: The gaseous pollutants include compounds of sulfur (sulfur dioxide – SO_2, and sulfur trioxide – SO_3), carbon monoxide – CO, nitrogen compounds (nitrogen monoxide – NO, nitrogen dioxide – NO_2, and nitrogen trioxide – N_2O_3), organic compounds (hydrocarbons, volatile organic compounds, polycyclic aromatic hydrocarbons, halogen derivatives, etc.), halogenated compounds (HF and HCl) and materials with specific scents. Secondary pollutants are created under the influence of heat, chemical or photo-chemical reaction.

Table 1

Pollutants to be monitored by automatic monitored

Sulphur dioxide (SO_2) 1.30 kT yearly	
Nitrogen dioxide 39 kT yearly	
Ozone	
Solid particle size of 10 μm (PM10)	
Solid particle size of 25 μm (PM2.5)	
NMVOC	Benzene
	Toulene
	Ethyl-benzene
	Ortho- and paraxylene

Table 2

Upper limits of pollutants to be monitored by automatic monitored (kT yearly)

SO_2	NO_x	VOC
130	39	30

Suspended particles: The composition of suspended particles in the air are covered suspended particles (TSP), PM10 (PM with a mean aerodynamic diameter less than 10 μm), PM2.5 (PM with a mean aerodynamic diameter less than 2.5 μm), and fine particles originating from diesel engines, floating ash from coal, mineral dust (coal, asbestos, silicate, cement), metal dust and fumes (e.g., zinc, copper, iron and lead), acid aerosols (e.g. sulfur acid), fluoride particles, pigment color, etc.

"Summer smog" occurs only in summer, under certain meteorological conditions, and a mixture of oxidants etc.. Photochemical oxidants are arising as a product of the action of ultraviolet radiation on the mixture of present pollutants (nitrogen oxides, hydrocarbons). Under the influence of sunlight the nitrogen dioxide breaks down and releases oxygen atom that is reactive and creates ozone.

3. AIR QUALITY AND HEALTH EFFECTS

Air pollution, indoors and outdoors, is a major environmental health problem affecting all appropriate developed and in developing countries. In 2005 the World Health Organization (WHO) developed guidelines for air quality (AQGs) de-

signed to provide global guidance to reduce the health impact of air pollution. Guidelines were originally developed in 1987 and later updated in 1997 for European needs. The new principles (2005) are related to the world and they are based on expert evaluation of current scientific evidence. They recommend revized limits for the concentration of selected air pollutants: suspended particles (PM), ozone (O_3), nitrogen dioxide (NO_2) and sulfur dioxide (SO_2), applied in all WHO regions.

The effects of PM particles on human health caused on different levels of exposure are filled by most urban and rural populations in developed and developing countries. Chronic exposure to suspended particles leads to an increased risk of developing cardiovascular and respiratory diseases and lung cancer. In developing countries, exposure to pollutants substances from the combustion of solid fuels indoors, on open fires or traditional stoves, increases the risk of acute lower respiratory infections and is associated with mortality in young children; air pollution indoors caused by use of solid fuels is also a major risk factor for chronic obstructive pulmonary disease and lung cancer in adults. Mortality in cities with high levels of pollution is greater for 15–20% compared to that observed in relatively cleaner cities. Even in the EU, average life expectancy is 8.6 months lower due to exposure to PM2.5 produced by human activities (data from WHO 2011) .

4. CLIMATIC FEATURES

Situated in the southeastern part of Europe or in the center of the Balkans, Macedonia, although landlocked it has quite favorable geographical location. The country has regions with different climates: continental, Mediterranean, mountain air and their subtypes. On the temperature of the air in the Republic of Macedonia affect latitude, relief structure, the distance from the seas and oceans, the presence of water reservoirs, the degree of forest expanse in certain areas, etc. Depending on these factors it's occur temperature changes as well in horizontal and vertical direction.

In Macedonia the average yearly temperature is 11.5°C. The warmest month of the year is July with an average temperature of 22.1°C and the coldest month is January with a average temperature of 0.3°C. The air temperature in the country is decreasing with increasing of the altitude on every 100 m for 0.39°C. In winter sometimes there is an effect of temperature inversion valleys have smaller temperature values, while the high mountains have larger temperature values. Cold air can keep while in the valleys, where despite the extremely low temperatures and can form dense fogs, while the heights of the surrounding mountains have lot of sunshine and heat. Characteristic to mention is the duration of frosty days, or days when the air temperature is below 0°C – the lowest number of frosty days is in Dojran only 32 days, while that number in Lazaropole is 134 frosty days.

Precipitation in the country is quite improperly spaced, with an yearly mean value of 500 to 1000 mm. Most rains fall in autumn and winter months – with a maximum in November, and minimum in summer months – with a maximum in August. The relative humidity in the country's largest in winter months especially in December with 84%, and lowest in the summer months, in July up to 57%.

The yearly amount of solar splendor ranges from 2,100 to 2,450 hours and is close depending on latitude and altitude.

5. DESCRIPTION OF CONSUMER AREA FOR USE OF THERMAL ENERGY

The subject matter of this paper is part of the urban area, e.g. consumption in certain defined area, composed of public facilities (primary and secondary schools, kindergartens, dormitories, administrative buildings, libraries, etc.), objects of public interest (ambulance, post office, banks, gyms, etc.), other major facilities (hotels, restaurants, administrative buildings of private companies, etc.), commercial entities and residential buildings (individual and collective). The buildings are mostly of solid construction, especially larger facilities, collective residential buildings and a large part of individual residential buildings. Most of the examined area is connected to the central heating system while the lower part, mostly households, have individual heating systems, mostly are using boilers that are powered by electricity, heating fuel oil (EL), firewood and coal fraction, while rest of residents the heating of homes have settled with solid fuel stoves and electricity panels. An installation for heating by applying modern economical heating system is negligible.

According to the existing regulations in RM the heating season begins when the temperature of the outside air at 21 p.m, three consecutive days will fall under 12°C, and ends when the outside air temperature under the same circumstances rise above 12°C. Thus usually the heating season starts

on October 15th and ends on April 15 next year, with an average outdoor temperature during the heating of 6°C, with a daily average of 15 hours warming and theoretical duration of the heating season of 182 days.

In the examined area there is district heating system with plant comprised with three hot water boilers in block construction. Two boilers are with a capacity of 6 MW (with consumption of 1000 kg/h heavy oil or 1155 Nm^3/h natural gas), and one boiler with capacity of 16.3 MW (with consumption of 1659 kg/h heavy oil or 1900 Nm^3/h natural gas), or a total plant capacity of 28.3 MW. Plants originally worked with heavy oil, but after performed adaptation an old heavy oil burners of the two smaller boilers was replaced with new burners for combustion of natural gas only, while in the larger capacity boiler with appropriate reconstruction was inserted two combined burners with the possibility of using fuel gas / heavy oil alternatively.

In order to improve the quality and efficiency of heating, there is set up different modes of operation of the plant, where qualitative delivery of heat is directly dependent on the outside air temperature. During their daily work, the plant operates in two modes: daily regimen and reduced mode. With the introduction of these two modes will allow improvement of the quality of heating facilities in particular exerted energy on a daily basis. The Figure 1 is represented delivery of heat for each day of the heating season, while the share given from each boiler at same production is respectively shown. The energy deposited by the plant provides uniform heating of all facilities and maintenance of stable parameters throughout the day.

When analyzing the emissions of the combustion products from the operation of the plant there are considered three scenarios of operation of boilers depending on the plant used fuel: only heavy oil, combined heavy oil / natural gas and natural gas only, under the same external temperature terms and heating needs. From the attached diagrams is evident that emissions of harmful substances SO_2, NO_x, suspended particles are far more for production, transmission and distribution of heat energy per unit with using heavy oil as fuel compared with emissions of harmful substances in the production of the same amount of heat energy while using natural gas.

While emissions of CO are inversely proportional in terms of SO_2, NO_x, suspended particles, emissions are higher when using natural gas than the combined use of fuel oil / natural gas. You can see that work only with fuel oil as fuel is worst in terms of emissions of harmful substances and it is justified tendency to use natural gas as fuel.

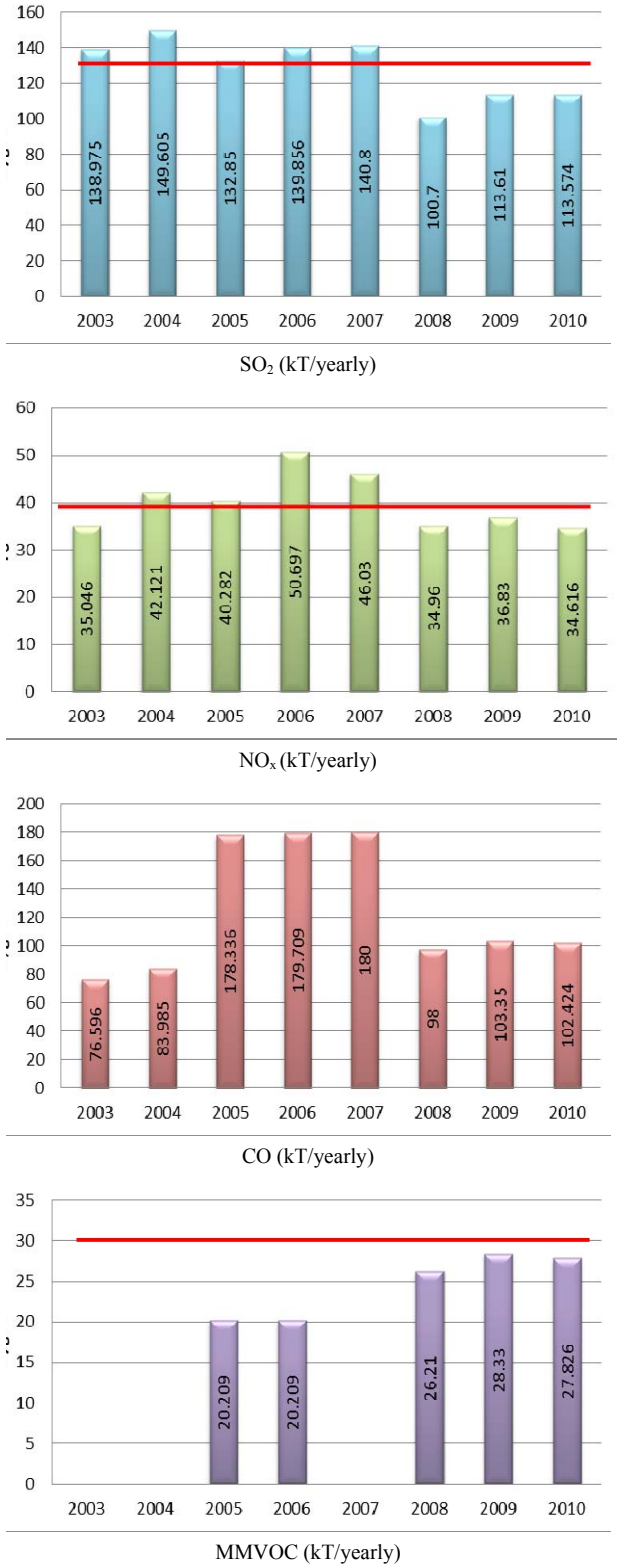

Fig. 1. Comparison of total emissions in kT for the period 2003–2010, with an upper limit on pollutants respectively (data from reports of Ministry for Environment of RM)

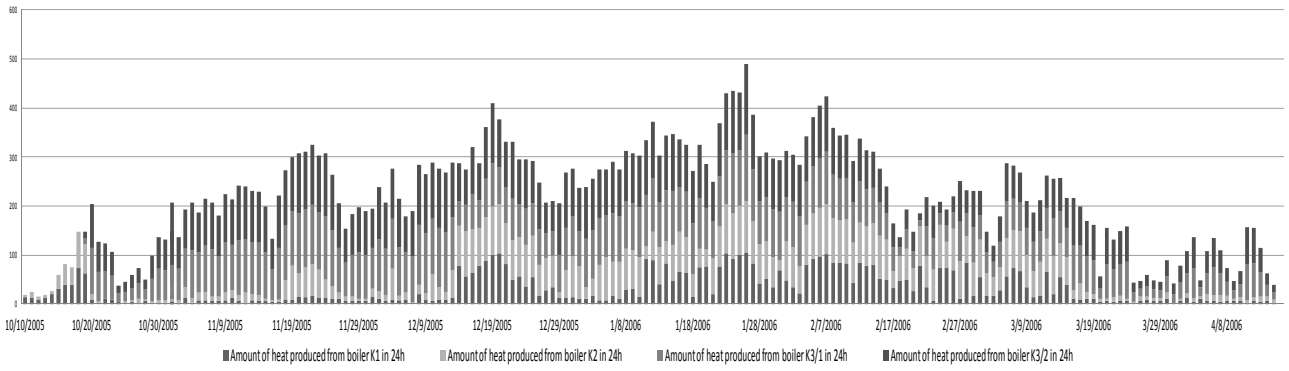

Fig. 2. Daily plant production of heat from each boiler in heating season (MW/24 h)

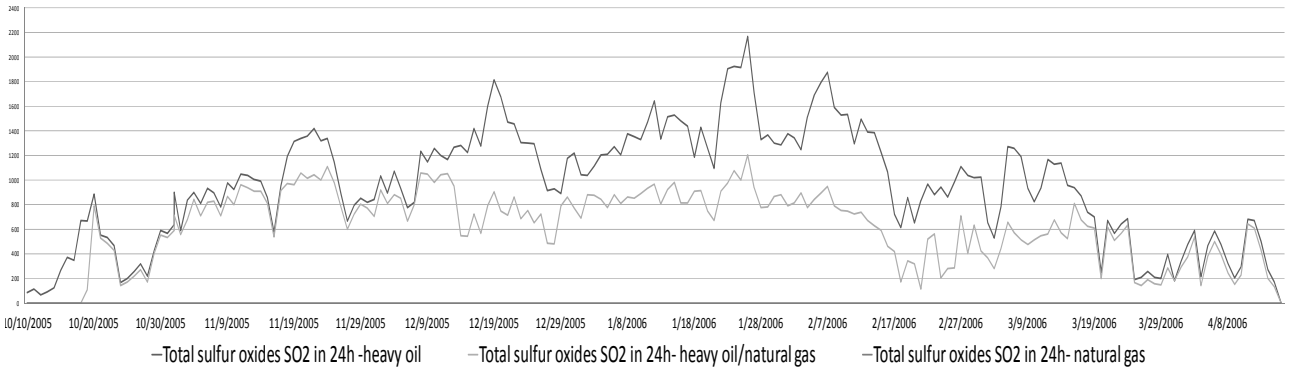

Fig. 3. Total emissions of SO_2 (t/24h) for every day of the heating season

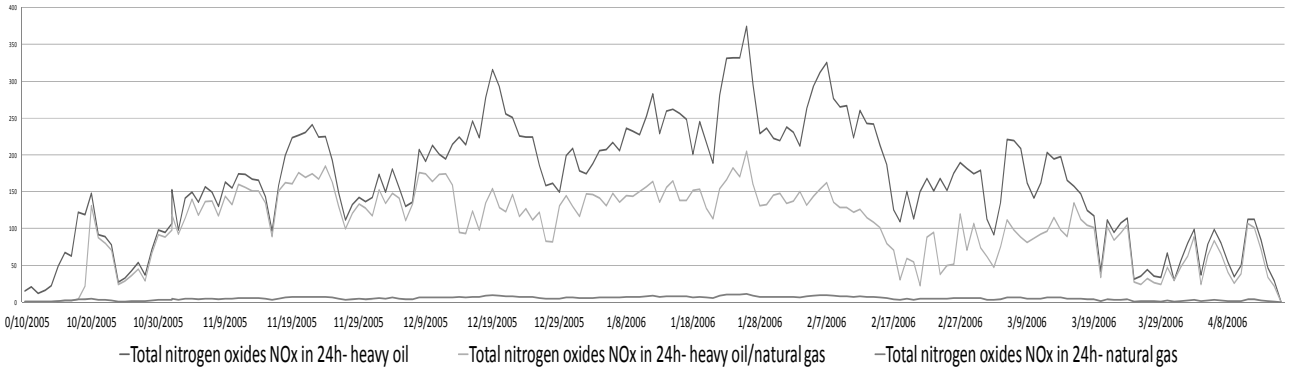

Fig. 4. Total emissions of NO_x [t/24h] for every day of the heating season

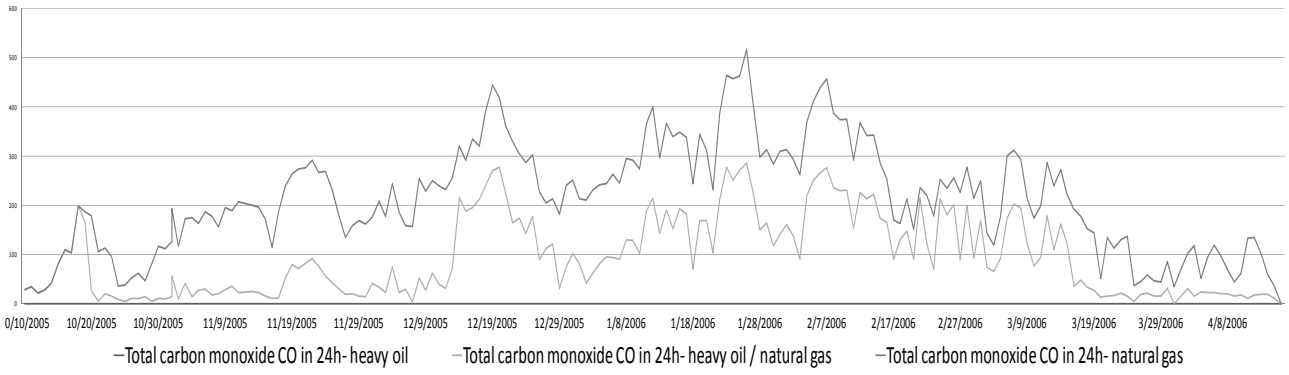

Fig. 5. Total emissions of CO [kg/24h] for every day of the heating season

For boilers of older production, often energy from fuel is underused since the temperature of the exhaust gas is relatively high and it is discharged into the environment. In recent years many improvements have been made and necessary changes to the central heating system, with the sole aim to improve the utilization of thermal energy supplied to final consumers, and thereby reduce emissions of greenhouse gases and the environmental impact.

6. OPPORTUNITIES FOR APPLICATION OF NATURAL GAS

From the analysis of the area it can be concluded that the structure of consumers is diverse, which the greater extent energy demand could be substituted with natural gas. The dominance of housing space in terms of industrial and public facilities in the area, leads to the conclusion that it will have uneven consumption of natural gas during the year, emphasized the need during the heating season. In summer, not taking in account the needs of industry, mostly natural gas consumption will be reduced and it will be used only to meet the needs of SHW and partially for cooking, on the other hand in the winter it will be increased even triple because of needs for heat production.

The concern in this paper are households needs, using as input the necessary data relevant to the calculation of the consumption of natural gas in the examined area where was taken following parameters: average number of apartments in an urban unit, maximum gas consumption in an average apartment, maximum gas consumption of individual devices embedded in an average apartment, and the coefficient of simultaneity of consumers within an urban environment. Given the structure and type of facilities for collective and individual housing in the examined area, the average apartment regarded residential area is with approximately 80 m^2 (apartment with three rooms), and inside is living an average family with four members. The average apartment is provided natural gas to be used primarily for heating in winter, preparation of sanitary hot water and cooking.

The yearly amount of delivered natural gas to end-user can predict when we will take in consideration the yearly consumption of thermal energy towards the aforementioned conditions for the heating season and the anticipated needs of the heat production of domestic hot water/cooking (which monthly amount would be 170 kWh for SHW and about 150 kWh for cooking to meet the needs of an average apartment and the average family). For collective residential buildings is more favorably to locally produce heat in a highly efficient gas boilers by measuring the thermal energy delivered at the facility/user, while individual residential buildings for heating purposes would use own small gas boilers. An additional factor to invest in a new system that uses natural gas is more comfort in terms of the earlier way of providing a heat.

Assessment of environmental change with increased use of natural gas by the end users, can be achieved on the basis of comparison with previous methods of supplying heat witch directly affect on global and local environment. The comparison should be done in terms of competing ways to meet the needs for thermal energy, i.e. electricity, heat of central heating systems, thermal energy from local sources witch for the production of thermal energy are using fuel oil EL, LPG, wood for burning or other solid fuels.

Price calculation for thermal energy produced by fuel type (energy) and types of combustion is based on the purchase price of energy medium, their calorific value and coefficient of utilization of boiler, without taking in consideration cost of logistics, transportation and storage, for current period in 2012 at Macedonia is given in Table 3.

We should take into account the fact that firewood is the cheapest medium but not possible any automation system, see the micro and mini boilers while using fruit seeds as fuel has limited quantitative capacity in the country. While firewood is still the cheapest medium in the production of thermal energy it is characterized by high emissions of harmful substances and solid particles.

It is undisputed that the substitution of electricity with natural gas to provide heat energy needs of the consumer greatly reduces impact on the environment. Households in the RM are characterized by relatively high average monthly consumption of electricity, due largely to the use of electricity for heating homes in the winter months. Increased consumption is caused by lack of alternative, lack of developed distribution network of natural gas, poor thermal insulation of buildings for housing and the high cost of insulation materials in construction.

According to the State Statistical Office, in 2012, the Republic of Macedonia, the gross national electricity consumption in the amount of 8.930.977 MWh, 70.1% are supplied from domestic production and 29.9 % of imports.

Table 3

*Cost of thermal energy by type of fuel for March 2012**

No	Fuel type	Coefficient of utilization of plant η	Retail price without VAT EUR/…	Price for a private facility EUR/kWh	Price for office building EUR/kWh
1.	Electricity (12 h per day/4 h night period + power engaged	1.00	Private 0.031/0/062	0.085	0.146
2.	Fuel oil EL	0.90	0.895 EUR/l	0.104	0.106
3.	Heavy oil	0.90	0.779 EUR/kg	0.079	0.092
4.	Natural gas	0.95	0.503 EUR/dm^3 (l)	0.053	0.067
5.	Butane–propane	0.95	0.773 EUR/dm^3 (l)	0.063	0.073
6.	Coil (1500 kcal/t)	0.80	95.935 EUR/t	0.067	0.067
7.	Heat pump	2.00		0.043	0.073
8.	Firewood	0.85	57.561 EUR/m^3	0.011	0.011
9.	Fruit seeds	0.90	50.407 EUR/t	0.012	0.012
10.	Wooden pellets	0.90	201.627 EUR/t	0.045	0.045
11.	Biomass (pellets)	0.90	100.814 EUR/t	0.023	0.023
12.	Biomass (chips)	0.90	75.61 EUR/t	0.017	0.017
13.	District heating (by heat meter + power engaged)	1.00		0.079	0.157

* Data is taken from the published text of Stefan Pop Dučev in magazine press issued by Chamber of OAI

The biggest consumers of electricity in 2012 are households with 36.5%, industrial sectors (energy sector plus industry) with 26.6%, and other sectors with 17.2% of gross national electricity consumption. 80% of domestic electricity production is realized in thermal power plants, and only 20% of the hydropower facilities. In thermal power plants as a primary fuel for electricity generation is using coal. Emissions of harmful substances SO_2, NO_x, suspended particles are far more in production, transmission and distribution of electricity for single amount in relation to the emission of harmful substances in the production of the same amount of thermal energy from a local source that uses natural gas.

Thermal energy from the central heating system is mostly produced from natural gas. According to the State Statistical Office for 2012, in the RM are produced 2.463.391 GJ of heat: 2.4% coal, 24.4% of oil products and 73.2% of natural gas. Consumption of thermal energy production is 0.4% and the loss distribution is 11.5% of total production. The biggest consumers of thermal energy in 2012 with 1.430.926 GJ are households and other sectors with 615.148 GJ.

7. LEVEL OF EMISSIONS

Mostly in combustion emissions depend on the equipment, the quality of fuel and the combustion process. The Table attached is showing typical emission of products of combustion in terms of different types of fuels.

From the attached Tables 4 and 5 can be noted that natural gas has the lowest emission levels of pollutants (CO_2, SO_2 and suspended particles), even compared with some fuel ratio is several fold lower respectively. The frequently emissions of suspended particles from combustion of natural gas tend to be extremely low, typically less than 3.6 mg/kWh, while the coal they are very high as 430 mg/kWh or more if the equipment is older technology. An emission level of NO_x in the flue gas depends on the equipment used for combustion, fuel type and largely on how the system operates.

Confirmation of reduced emissions of pollutants by changing drive fuel boilers (oil/gas) are 3, 4, 5 accompanying charts of the plant operation. Notably is the reduction of emissions, and accordingly the impact on the environment, with the use of natural gas.

Table 4

*Emissions from different types of fuels**

Fuel type	Heating value MJ/kg_B	C-content kg_C/kg_B	CO_2-emission kg_{CO_2}/KWh	
Natural gas	39.6	0.59	0.20	0.055
Fuel oil El	42.7	0.86	0.37	0.075
Hard coil	29.7	0.77	0.34	0.095
Brown coil	8.5	0.28	0.43	0.12
Firewood	15	0.5	0.43	0.12
Electricity	–	–	0.56	0.22

* Data taken from the text published by the University of Magdeburg – Germany, entitled Control of air pollution

Table 5

*Emissions from different types of fuels**

Fuel type	Emisions (mg/kWh)	
	SO_2	Suspended particles
Coil	3250	430
Fuel oil EL	500	18
Natural gas	3.6	3.6

* Data taken from the published text of Stefan Pop Dučev in magazine press issued by Chamber of OAI

It should be noted that it is necessary modernization of facilities because the level of performance of the last generation of heat generators for use in district heating systems is significantly higher than the boilers in heating plants that are outdated technology and installed more than 20 years. Thus it can be concluded that with appropriate modernization and application of the latest generation of generators will have a significantly reduced impact on the environment.

The main difference in the effective use of thermal energy generated from natural gas, from district heating system and from local system is the loss that occurs in the distribution of thermal energy from plant where it's produced to the end user. For smaller district heating systems these losses are 6% while for larger they reach to 16%. With use of local systems for heat production, the heat loss from the distribution is eliminated, making a direct influence on reducing the cost of heating for end user. The effects of reducing the consumption of natural gas are directly reflected on emission reductions at municipal level.

The data in Tables 6 and 7 are designed for an average apartment with an area of 80 m^2 (with specific heat demand of 80 W/m^2) in which the average family of four members is living in a period of heating season. The Tables 1 contains following data: Planned a monthly consumption of thermal energy towards the aforementioned conditions for the heating season (cca 940 kWh) and predicted needs of heat production of domestic hot water / cooking (which amount will be 170 monthly kWh for SHW and about 150 kWh for cooking for an described average apartment and the average family). In the average apartment natural gas is planned to be used primarily for heating in winter, preparation of SHW and cooking. For other types of energy they are provided to be used exclusively in heating purposes, and energy needs for cooking and SHW are satisfied with the application of electricity.

Table 6

Total monthly energy costs for 4 members family accommodated in the 80 m^2 apartment

Fuel type	Price for a private facility	Monthly costs for:			Total monthly energy costs
		heating	SHW	cooking	
	EUR/kWh	EUR	EUR	EUR	EUR
Elecricity (12 h per day/4 h night period + power engaged)	0.09	85	16	14	115
Fuel oil EL	0.11	104	16	14	134
Natural gas	0.06	57	11	9	77
Firewood	0.02	19	16	14	40
District heating (by heat meter + power engaged)	0.08	76	16	14	106

Table 7

Total emissions of CO_2 from energy needs of 4 member family accommodated in the 80 m^2 apartment

Fuel type	Emission	Emissions of monthly needs for:			Total montly emmissions
		heating	SHW	cooking	
	kg/kWh	kg	kg	kg	kg
Electricity	0.56	527	46	41	614
Fuel of oil El	0.27	256	46	41	341
Natural gas	0.20	188	34	30	252
Firewood	0.41	405	46	41	492
District heating	0.223	210	46	41	297

Figure 6 shows the economic viability of using natural gas. Use of natural gas instead of electricity will result in monthly financial savings of 38.46% instead of heating / electricity would result in a slightly lower monthly financial savings of 37.42%, while the biggest financial savings resulting from the use of natural gas instead of heating fuel oil EL/electricity espectable 47.44%.

By comparing the results obtained from the Figures 6 and 7 it can be seen that the percentage reduction of CO_2 emissions is not right proportional with financial savings expressed in percentage during replacement of energy medium with natural gas. The largest reduction in emissions we have with substitution of electricity with natural gas 58.95%, and with substitution of heating fuel oil EL/electricity we have 26.1%. The closest reduction we have with replacement of district heating/electricity because the boilers in the plant runs on natural gas, therefore mostly savings is due to the replacement of electricity used for the preparation of SHW and cooking.

Local production of heat with heating fuel oil EL, LPG and wood burning have lower energy efficiency of local production of thermal energy from natural gas, making use of natural gas has less appropriate environmental impact. A social benefit from the use of natural gas in providing the required amount of heat is reducing of environmental pollution.

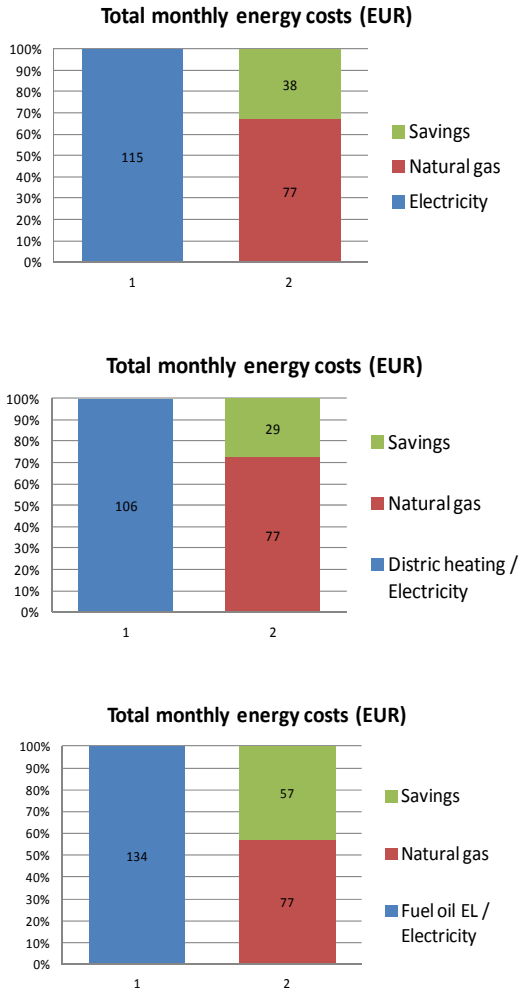

Fig. 6. Comparative data on total monthly energy costs by using natural gas and other fuels accordance to Table 6

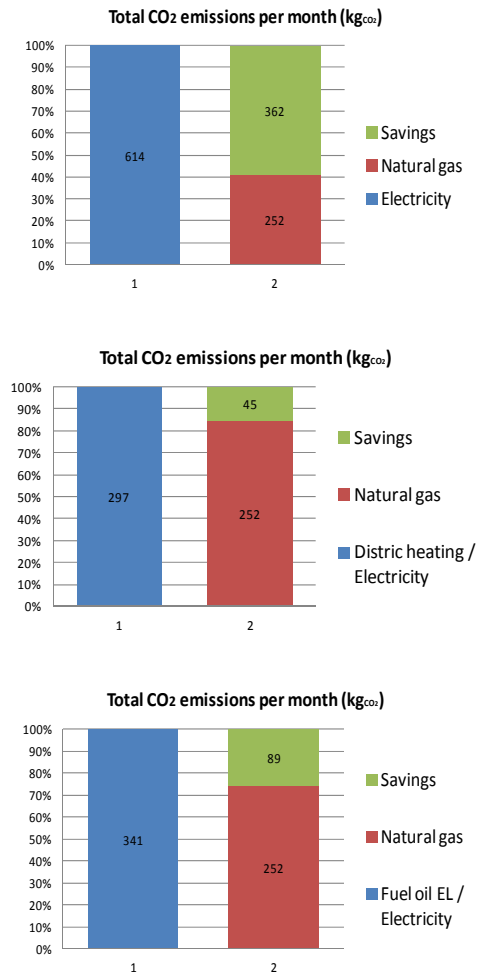

Fig. 7. Comparative data on CO_2 emissions on a monthly basis with the use of natural gas and other fuels accordance to Table 6

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Original scientific paper

SUSTAINABLE IMPROVEMENT OF THE ENERGY EFFICIENCY OF AN EXISTING BUILDING

Aleksandar Petrovski[1], Atanas Kočov[2], Valentina Zileska Pančovska[3]

[1] *"Ss Cyril and Methodius" University in Skopje, Faculty of Architecture, Blvd. Partizanski odredi 24, Skopje, Republic of Macedonia*
[2] *"Ss. Cyril and Methodius" University in Skopje, Faculty of Mechanical Engineering, Karpoš II bb, P.O. box 464, 1001 Skopje, Republic of Macedonia*
[3] *"Ss Cyril and Methodius" University in Skopje, Faculty of Civil Engineering, Blvd. Partizanski odredi 24, Skopje, Republic of Macedonia*
petrovski.aleksandar@arh.ukim.edu.mk

A b s t r a c t: The existing housing buildings are consumers of large quantities of energy due to the low thermal characteristics of the buildings envelope. The ground-floor housing buildings represent large percentage of the housing stock in Republic of Macedonia. Three possibilities for achieving environmental sustainability of a building are analyzed such as: improvement of the energy efficiency of the buildings walls, the windows and both options altogether. The possibilities consider the improvement of the energy performance of the facade related with financial issues such as bank credit and investment return. Autodesk Ecotect is used for the modelling and energy performance simulation. From the results it is concluded that the investment return period is very long and certain measures need to be taken such as decreasing the loans interest rate, decreasing the building cost and materials and providing possibilities for subsidy.

Key words: sustainability; building envelope; bank credit; return of investment

ОДРЖЛИВО ПОДОБРУВАЊЕ НА ЕНЕРГЕТСКАТА ЕФИКАСНОСТ НА ПОСТОЕН ОБЈЕКТ

А п с т р а к т: Постојните станбени објекти се потрошувачи на големи количества енергија поради слабите термички карактеристики на фасадата и покривот. Приземните станбени објекти се застапени во голем процент во целокупниот станбен фонд во Република Македонија. За постоен приземен објект се разгледувани три можности со цел постигнување одржливост на објектот во однос на околината, и тоа преку подобрување на енергетските карактеристики на надворешните ѕидови, на прозорците и двете опции заедно. Можностите се однесуваат на подобрување на енергетските перформанси на објектот поставени во релација со финансиските аспекти како што се банкарски кредити и враќање на инвестицијата. За моделирањето на енергетските перформанси на објектот е употребен софтверот Autodesk Ecotect. Од добиените резултати е заклучено дека рокот на враќањето на инвестиција е долг, поради што е потребно да се преземат чекори во однос на намалување на каматните стапки за кредити, намалување на градежните трошоци и создавање можности за субвенционирање.

Клучни зборови: одржливост; надворешни ѕидови на објект; кредити; враќање на инвестиција

1. INTRODUCTION

Modern society is confronted with transformation imposed by the climatic changes. The construction sector reached a consensus about the influence of the built environment in causing these climatic changes [1]. According to the studies of the yearly emission of CO_2 per capita, 30% from all the emissions are from the heating of buildings, 28% from the cars, etc. [5].

Construction industry is one of the most intensive industries participating with 50% of the resource consumption, 40% of the energy consumption and 50% in the creation of waste [9]. In Republic of Macedonia, in certain regions, 70–90% of the built fond is consisted of individual housing buildings [4]. Therefore, the focus of this paper is pointed towards this type of buildings. According to the State Statistical Office, there is an upward trend in the electrical energy demand in the households with a total use of 36.5% in 2012 of the gross-domestic energy demand [6]. The Strategy for energy efficiency in Republic of Macedonia anticipates that in all energy demand sectors, especially in the housing, savings should be made [7]. In this sector, the largest energy demand goes for heating and cooling with 71%, 17% for water heating, etc.

Sustainability as a concept is described with multiple definitions, and the most used one defines that the sustainability is satisfying the current needs without compromising the needs of the future generations. It is based on three principal segments: economic, social and environmental, often addressed as the "triple bottom line". The sustainability even if it is usually connected with the "green" movement, it recognizes the need for a healthy economy. It is not a marginal topic, but contrary, with its concepts it offers paced development of all industries. Therefore, the fastest growing sector in the energetics is the exploitation of the wind energy, in the tourism, it is the ecotourism, in the investment sector are the social responsible investments [1]. The participants in the sustainable construction have to have in mind principal factors which include in themselves aspects such as: design and building management, choice of materials, interaction with the city and economic development [2]. Sustainable buildings have a positive influence in the surroundings because they are designed to be built with recycled materials or materials capable for recycling, while their production demands low CO_2 emission [3]. Because of the contemporary demands, the construction industry goes through a process of evolution and transformation of the current work methods and development of new technologies as the demand for low-carbon buildings enhances. The buildings influence the environment in two ways. The first one is by the exploitation of natural resources and the second is by the use of unrenewable energy referred to as environment deterioration [17]. Therefore, a lot of attention should be given to these two segments especially regarding the origin of materials, their appropriate use with ultimate purpose of decreasing the exploitation of non-renewable resources.

The goal of this research is to examine the possibilities for financing a reconstruction of a building facade thus improving the buildings sustainability. A model of a ground floor housing building is analyzed and several possibilities for a reconstruction are considered. Aspects of potential energy savings, financial investment, credit possibilities are inspected. A techno-economic analysis is conducted regarding the possibilities for ROI (return of investment). The methodology of the conducted research is based on:

1. Gaining climatological data from the software Meteonorm, needed for simulation of the environmental conditions for the area where the building is placed.

2. Analysis of the energy performance of the building through a software model in Autodesk Ecotect. The energy performance simulation would be observed without the use of active HVAC systems with an intention to measure the passive behaviour of the building. Most used method for measuring the buildings performance is his energy demand and/or number of (un)comfortable hours [11].

3. Analysis of the sustainability of the facade reconstruction through parameters such as cost of the reconstruction, credit possibilities and ROI.

2. ANALYSIS

For testing the proposed methodology a building constructed in 1963 is chosen. It has potential for sustainability improvement considering the period in which it is built and the used materials. The building is placed in Skopje, in the Vlae neighbourhood, built after the Skopje earthquake in 1963. This neighbourhood is first planned with the Skopje's Master plan for the period of 1963–1985 where is predicted renewal of the built fund which was 65% destroyed from the earthquake. For the need of fast population settlement a prefabricated way of constructing was used and 15.000 housing buildings were erected, among which is the neighbourhood of Vlae [13]. The sustainability improvement of this kind of building offers possibilities for tackling the sustainability of the whole area, meaning that with micro-interventions, macro -implications on an urban level are induced.

The building analyzed is prefabricated type EDILIT, constructed from light weight gas-concrete panels 15 cm thick, and connected to each other by a thin reinforced concrete joint built on site. The physical and thermal characteristics of these panels are not entirely known because there is no technical documentation from this period. For a precise determination of their thermal characteristics, an in-situ thermo-graphical measurement is needed. For those reasons, in the calculation of this research, thermal characteristics of contemporary panels made of gas-concrete are being used. The floor is constructed as a reinforced concrete slab, laid on terrain with a final layer of wood parquet placed on cement screed. The roof is constructed from wooden beams, with roofing made of asbestos-cement boards. The room height is defined with the ceiling constructed of modular panels upon which a 5 cm glass wool is laid. This kind of ceiling and isolation placement defines the thermal zone for calculation of the energy demand for heating and cooling of the interior. The building is L-shaped flanked on two sides by neighbours as shown in Fig.1.

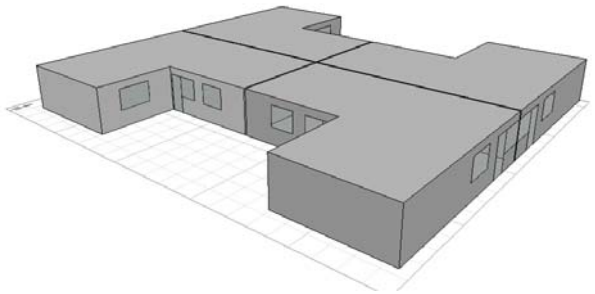

Fig. 1. Model of the analyzed building.
(Source: From own research)

The possibilities of sustainability improvement of the building through renovation of its envelope are based on three options shown on Table 1.

In the option 1 improvement of the thermal transmittance of the envelope are planned. In the option 2 replacement of the windows with $U = 5.1$ W/m^{2}K is planned, with windows with total U value of the whole windows of 1.2 W/m^{2}K and low-E coating. The option 3 include the two aforementioned options altogether. The choice of these options is based on the fact that they are the most common way of renovating the buildings in the country. The first option is modified, because in the common renovating construction works are planned for the exterior walls or/and rood but not for the floor. In the analysis the whole envelope is treated thus achieving low thermal transmittance of $U = 0.254$ W/m^{2}K.

Table 1

Renovating options

Options	Construction cost (MKD with VAT)
1. Insulation in the building envelope	491.398
2. Window replacement	136.290
3. Construction of option 1 and option 2	627.688

Source: From own research

Instalment of a 15 cm insulation is planned in the roof, floor and facade. The choice of isolation is from the programme of the manufacturer Knauf Insulation because of its sustainable characteristics. It is a product of the innovative ECOSE technology based on renewable materials and at the same time avoiding all the malign substances such as formaldehydes used as binder. This technology has a positive environmental influence by reducing the embodied energy in the insulation material for up to 70% compared with standard materials using conventional binders. The embodied energy is interlinked with the operative energy and it is a very important factor that needs to be taken into consideration, considering that the operational energy is decreasing (by efficient improvements), the embodied energy gains in significant even more [16]. The rock wool produced with the ECOSE technology has a 0 global warming potential (GWP) and ozone depletion potential (ODP) [14].

The mineral rock wool insulation type FKD-S is planned for instalment in the facade. It is planned to be constructed as contact facade with final facade mortar from the same manufacturer. For reduction of the thermal transmittance of the floor while also satisfying the load carrying demands, rock wool type KR plus is used. The glass wool type Classic 042 is used for reducing the transmittance of the ceiling, and for the facade walls towards the neighbour's a lining of insulation type TI 140 is planned. The details are designed according to the technical guide provided by the manufacturer, with a purpose to secure the building from the malevolent influence of the diffusing processes through the buildings envelope [18].

The results from the conducted analysis of energy performance of the building are shown in

Figure 2 from which it can be concluded that the decrease of energy losses in the reconstruction in option 1 is larger that in option 2. The existing windows have much larger coefficient of thermal transmittance, meaning that through them it occurs a large heat flow, and an expected result of the renovation would be to have largest saving with their replacement.

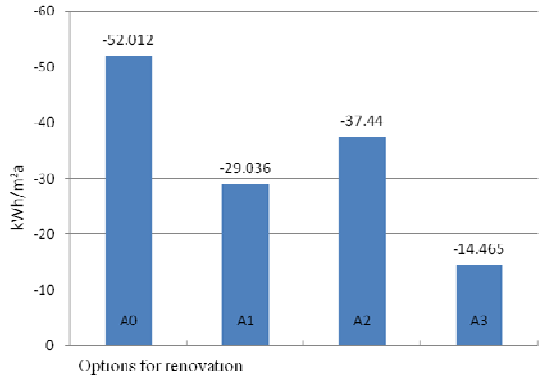

Fig. 2. Model of the analyzed building
(Source: From own research)

But, because of the large participation of the wall area in the total area of the envelope with 95.8%, while the windows participate with 4.2%, the largest heat losses are through the opaque surfaces. The total yearly consumption of heating and cooling energy is shown in Table 2.

Table 2

Energy and financial savings

	Energy consump kWh.a	Total yearly cost MKD	Yearly savings MKD	Monthly savings MKD
A0 – existing build.	5617	44.907	0	0
A1 – option 1	3136	25.072	19.835	1653
A2 – option 2	4043	32.323	12.584	1048
A3 – option 3	1562	12.488	32.419	2101

Source: From own research.

In Table 2 are shown the total energy consumption, yearly cost, yearly and monthly savings, from which it can be concluded that the largest energy savings are in the Option 3. The total energy costs are calculated according to the current energy price of 0.13 €/kWh (7.9 MKD/kWh), with an expected tendency for its increase. In the next step of this research an analysis is conducted on the possibilities of bank credits and ROI according to the monthly annuity and the monthly energy savings.

3. INVESTMENT SUSTAINABILITY

In Republic of Macedonia the banks offer different credit options for realizing such a renovation. The loans can be met under the names as "green" credit or consumer credits. For fulfilling the right of taking credit, the borrower should meet certain demands such as: being employed (in the private or public sector, from which the interest rate depends), salary from which the payment period depends, possibilities for a co-signer, etc. Depending of the bank, the monthly annuity should be covered by 40–56% of the monthly net-salary of the borrower.

Table 3

Interest rate

	Option 1	Option 2	Option 3
Credit value	491.398	136.290	627.688
Interest rate		6.55%	
Number of payments		72	
Payment value	8.272	2.294	10.566
Total payment value	595.588	165.187	760.776
Total interest value	104.190	28.897	133.088

Source: From own research

The user of the existing building has a salary of 26.000 MKD, which are 23% larger than the average net-salary in the country [15]. According to this, the minimal payment period which the banks approve is from 6 until 30 years.

The interest rate with a denar exchange clause is 6.5%, 7.9% and 8.5%. The maximum amount for a loan can be until 600 000 – 9 000 000 MKD, and therefore only the banks that finance the largest investment, such as Option 3, are considered.

The loan value, interest rate, payment and total payment value are shown in Table 3. To calculate the ROI it is needed to compare the yearly energy savings of the renovation with the total payment value as shown in Table 4.

The simple ROI is calculated as a quotient of the total payment value and the yearly energy savings. From the values shown in Table 4 it can be

concluded that the ROI is shortest in Option 2, when only the windows are replaced, while the largest ROI is in Option 3.

Table 4

Interest rate

	Total payment value (MKD)	Yearly energy savings (MKD)	ROI (years)
Option 1	595,588	19,835	30
Option 2	165,187	12,584	13.1
Option 3	760,776	32,419	23.4

Source: From own research

4. CONCLUSIONS

This paper analyzes the possibilities of energy efficiency and therefore sustainability improvement of an existing buildings while considering the credit offers from the banks in the country. The investment is being approached in three options for renovation of the building. From the gained results it is concluded that the payment period is large, from 13 until 30 years. The long ROI is due to the fact that the building has small floor surface area thus having small energy demand and consumption. Although the energy savings on a yearly basis are decreased for 30–70% depending on the renovation option, the savings are small compared with the investment. Therefore certain measures should be considered stimulating users initiating such renovation. Possibilities for decreasing construction cost and insulation materials should be explored, as well as decreasing the interest rate and providing state subsidy for carrying out such construction renovation. By implementation of these type of measures the country enables conditions for transforming the buildings into energy efficient and sustainable ones with the decrease of their monthly CO_2 emission. Also opportunities for project financing should be made, which is different from the classic loan system, where from the success of the project depends the success of the investment. With these improvements and changes, certain conditions are provided for a transformation of the current consumer, inefficient society into a sustainable society.

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Original scientific paper

DEVELOPMENT OF LIFE CYCLE COSTING FRAMEWORK FOR USER'S COSTS IN MOTOR VEHICLES

Kristina Jakimovska, Igor Gjurkov

"Ss. Cyril and Methodius" University in Skopje, Faculty of Mechanical Engineering,
Karpoš II. bb, P.O. box 464, 1001 Skopje, Republic of Macedonia
kristina.jakimovska@mf.edu.mk // igor.gjurkov@mf.edu.mk

A b s t r a c t: This research is made on user's costs of three different vehicles in a vehicle fleet in Macedonia. Various methods of maintenance such as preventive and corrective maintenance are taken into consideration. A Life Cycle Cost (LCC) model is a simplified representation of the real system. Its function is to abstract the salient features and aspects of the product and to translate them into a cost figure. A Life Cycle Cost (LCC) analysis is a process of identifying and evaluating costs associated with acquisition and ownership of a product during its life cycle. This article shows a LCC model of vehicle ownership costs. According to this model a separate LCC analysis is made for each vehicle and for three different regimes of exploitation.

Key words: Life Cycle Cost – LCC; LCC model, availability; ownership cost; user's total cost

РАЗВОЈ НА СТРУКТУРА НА ТРОШОЦИ НА ЖИВОТЕН ЦИКЛУС ВО ПОГЛЕД НА ТРОШОЦИТЕ НА КОРИСНИЦИТЕ НА МОТОРНИТЕ ВОЗИЛА

А п с т р а к т: Направено е истражување на трошоците на корисник на три различни возила во возниот парк во Р. Македонија. Земени се предвид различни методи на одржување, како превентивно така и корективно одржување. Моделот на трошокот на животен циклус (LCC) е упростен приказ на реалниот систем. Неговата функција е да ги издвои важните карактеристики и аспекти на производот и да ги преточи во трошок. Анализата на трошокот на животен циклус (LCC) е процес на идентификување и оценување на трошоците поврзани со аквизицијата и користењето на производот во текот на неговиот животен циклус. Оваа статија презентира модел на трошоците за животниот циклус на моторно возило што ги сноси корисникот на возилото. Според овој модел е направена посебна анализа за секое возило и за три различни режими на експлоатација.

Клучни зборови: трошок на животен циклус – LCC; LCC модел; расположливост; цена за корисник: вкупен трошок на корисникот

1. INTRODUCTION

Many systems and products have been planned, designed, produced and operated with very little concern for their life-cycle cost (LCC) [7]. Today's customers require products which are reliable, products which can perform their functions safely and that can be easily maintained over their operating period.

2. LIFE CYCLE COST (LCC)

Life cycle cost is the total cost of ownership of machinery and equipment, including its cost of acquisition, operation, maintenance, conversion, and/or decommission (SAE, 1999). LCC helps change provincial perspectives for business issues with emphasis on enhancing economic competitiveness by working for the lowest long term cost of ownership which is not an easy answer to obtain [8]. As with most engineering tools, LCC provides best results when both engineering art and science are merged with good judgment to build a sound business case for action. LCC includes every cost that is appropriate and appropriateness changes with each specific case which is tailored to fit the situation.

Life Cycle Costs may help vehicle fleet's managers to envisage their costs for the next year and thus make them more successful in their budget making. Moreover, LCC awareness may also help vehicle manufacturers in making market competitive vehicles.

A primary guidance for a vehicle life cycle cost evaluation represents a standard [1]. According to such standard the vehicle life cycle costs can be divided into six periods:

1) concept and demand determination period,

2) design and development period,

3) manufacturing period,

4) installation period,

5) operating state and maintenance period,

6) disposal period.

The total costs incurred can be divided into two major parts, i.e. acquisition costs and ownership costs.

3. LIFE CYCLE COST (LCC) OF A VEHICLE

The LCC model, as is the case with any other model, is a simplified version of reality. It summarizes specific characteristics of the product during its life cycle and transforms them into costs. In order to be more realistic, it should [2]:

1) have all the characteristics of the product being analyzed, including the environment it is used in, maintenance strategy, operation, logistics, etc.;

2) be comprehensive and comprise all factors relevant to LCC;

3) be simple and easily understandable and allow for timely changing of decisions and making corrections or modifications;

4) be created in a way that will provide independent assessments of any LCC item.

In some cases a separate model may be required to make further researches of this issue, whereas in some other cases commercially accessible models may be applicable. A simple LCC model is in fact a calculation structure containing conditions and factors which may allow any cost assessment be referred to any LCC item contained therein. Each LCC model has its own flexibility and application. It is important to know the contents and conditions in which LCC models are applied in order to ensure the suitability of their application.

Before selecting a model, the scope of information needed should be compared with the results that are expected from such model application. A person acquainted with the respective model details should control it and establish all the applicable cost factors, empiric connections and other model constants and variables. Therefore, before applying any existing LCC model, it should be compared with the life cycle costs being assessed. To achieve that, costs factors and other parameters of a known example, along with an operating scenario, should be used to assess the scope within which such model may provide actual results.

Analytical studies and estimates of total costs are methods for finding life cycle costs. The objective of LCC analysis is to choose the most cost-effective approach from a series of alternatives so the least long-term cost of ownership is achieved [3]. LCC analysis helps engineers justify equipment and process selection based on total costs rather than initial purchase price. The sum of operation, maintenance, and disposal costs far exceed procurement costs. Life cycle costs are total costs estimated to be incurred in the design, development, production, operation, maintenance, support, and final disposal of the product over its anticipated useful life span.

In this article a LCC model of a vehicle considering the ownership costs is presented (Fig. 1). The ownership cost analysis considers the following three cases of various exploitation intensity [6] expressed in mileage travelled per year:

I – 10000 km per year (actual situation in this vehicle fleet),

II – 20000 km per year (recommended for this purpose),

III – 30000 km per year (intensive exploitation).

As it can be seen from Figure 1, user costs consist of the following four elements:

1) acquisition cost, i.e. vehicle purchase cost;

2) operation cost;

3) maintenance cost;

4) disposal cost.

As previously mentioned in this research three different vehicles from the Army's Vehicle Fleet in Macedonia have been taken, and they are:

- IVECO EURO CARGO 4×4
- IVECO EURO TRAKKER 4×4
- HMMWV M998

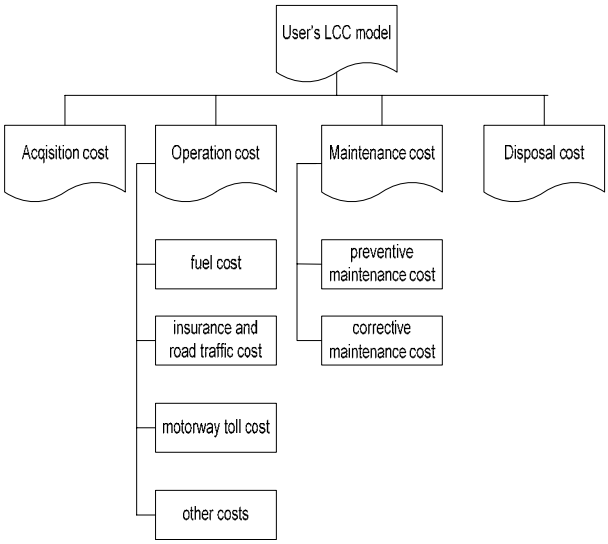

Fig. 1. LCC model of a vehicle

In this paper determination of the costs in the process of maintenance was conducted in three variants of the cost of labor as follows:

- Variant A – 1 working hour = 3 €, when the maintenance is done using resources from the Republic of Macedonia Army.
- Variant B – 1 working hour = 20 €, when the maintenance is done by an external organization, i.e. outsourcing maintenance.
- Variant C – 1 working hour = 50 €, when maintenance is done during a military mission abroad.

3.1. *Acquisition cost*

Acquisition cost, seeing from the manufacturer's point of view, can be expressed by the following equation [4]:

$$C_{PC} = C_{CD} + C_{DD} + C_M + C_S + C_{RG}, \quad (1)$$

where is: C_{CD} – costs on concept and demand determination period, C_{DD} – costs on vehicle proposal and development period, C_M – manufacture costs, C_S – vehicle sale period costs, C_{RG} – warranty period repair costs.

From the user's point of view, the acquisition cost is manifested through the purchase price of the vehicle.

3,2. *Operation cost*

Operation cost can be expressed by the following equation [4]:

$$C_{TRV} = C_G + C_{FOL} + C_{PA} + C_{OT} + C_{PT} + C_{VG}, \quad (2)$$

where is: C_G – fuel costs, C_{FOL} – working fluid costs, oil and motor lubricant costs (if there are not included in the maintenance stage), C_{PA} – tyres and accumulator battery costs (if there are not included in the maintenance stage), C_{OT} – vehicle insurance and road traffic tax costs, C_{PT} – motorway toll costs, C_{VG} – driver costs.

The vehicle fuel cost can be expressed by the following equation:

$$C_G = ge \cdot c_G \cdot S \ (€), \quad (3)$$

where is: ge (l/km) – fuel consumption for appropriate vehicle, c_G (€/l) – fuel single price, S (km) – vehicle mileage.

It should be noted that fuel consumption is basically a variable size and that it depends on vehicle technical condition. For a real display of such a cost, measuring should be made of the real fuel consumption in real exploitation conditions. Tyres and accumulator battery costs in this case are taken within corrective maintenance. Working fluid costs and oil and motor lubricant costs are not considered out of the maintenance process. Being Army vehicles, they, according to the regulations, are not burdened with insurance and tax duties and are free from motorway toll costs, so, these costs, along with drivers costs, are also not taken into account in the total cost.

3.3. *Maintenance cost*

Costs on vehicle preventive maintenance. In general, preventive maintenance costs are most accurately fixed according to the preventive maintenance schedule provided by vehicle manufacturers on the basis of their own market research and experience and targeted to as high competitiveness of their vehicles as possible.

The total cost amount required to be spent on preventive maintenance during the operating state apparently depends on the number of preventive maintenance operations required to be performed on the vehicle during its usage, and on the cost amount required for carrying out such preventive maintenance operations. For the preventive maintenance cost, the following equation can be used [4]:

$$C_{OMP} = t \cdot c_M, \quad (4)$$

where is: t – operating time, c_M – average costs on preventive maintenance applied to an operating time unit that these costs are dependent on the vehicle reliability level, i.e. failure rate.

Costs on vehicle corrective maintenance: The total cost amount necessary to spend on vehicle repairs during its operating state depends apparently on the number of failures which occur in the vehicle during its usage, and on the cost amount necessary to remove each failure. If the failure rate λ is regarded as a measure of reliability level, it is possible to use the following equation for repairing support costs [4]:

$$C_{OMC} = \lambda\, t\, c_R, \tag{5}$$

where is: λ – failure rate, t – operating time, c_R – average price of the vehicle, whereas it is estimated that the price is again dependent on the vehicle reliability level, i.e. on failure rate.

Total costs on vehicle maintenance. Vehicle maintenance generally comprises the following operations:

- care,
- preventive maintenance,
- corrective maintenance,
- overhauls (middle and large-scale),
- control / inspection,

$$C_{TC} = C_C + C_{OMP} + C_{OMC} + C_O + C_{CI}. \tag{6}$$

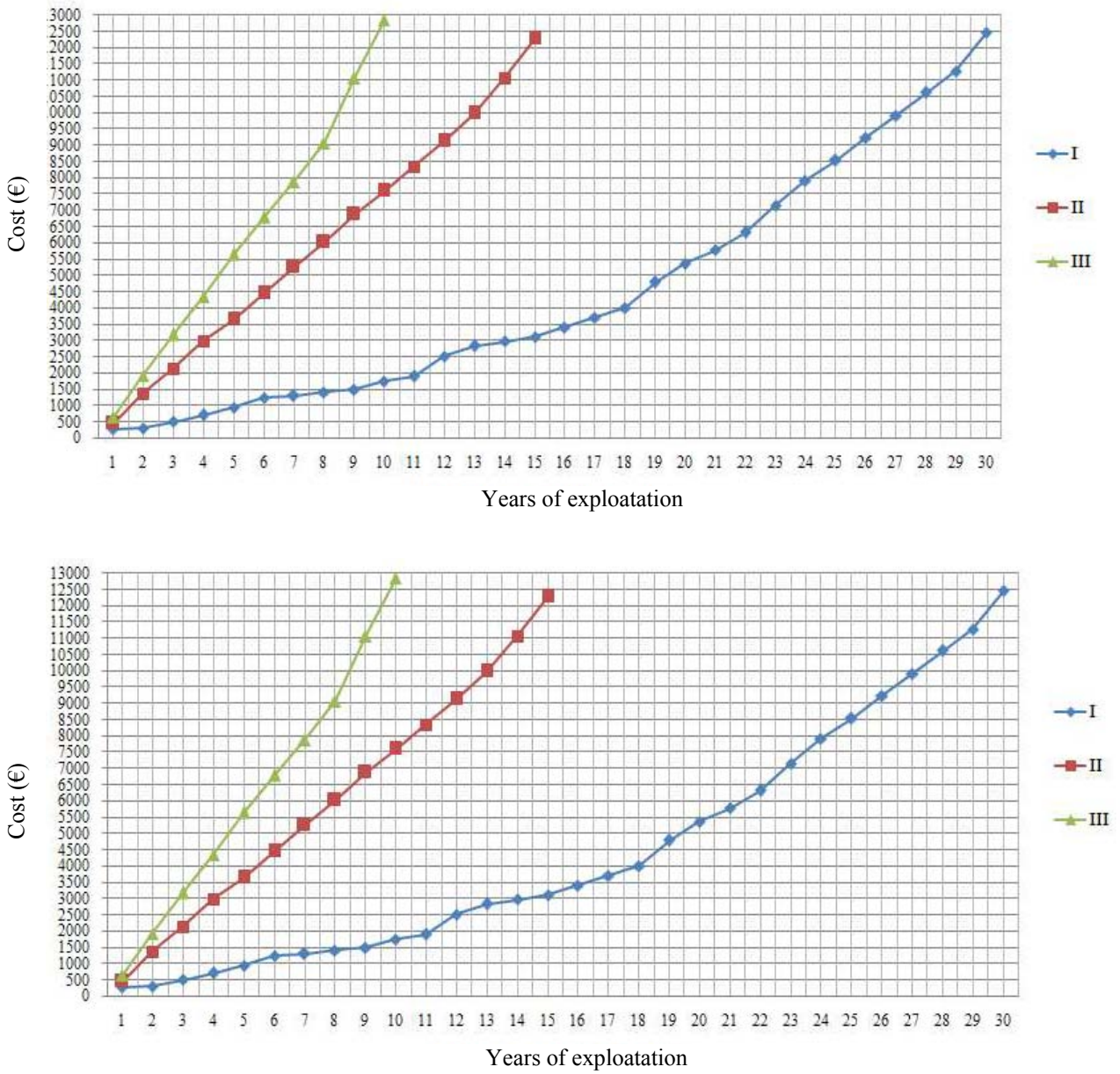

Fig. 2. Total maintenance cost on IVECO CARGO's maintenance [6]

3.4. *Amortization*

Amortization percent is set depending on vehicle category (kilometer-category – km·K) and vehicle exploitation period (age). Vehicle category is set for every individual vehicle type of the same brand according to the SUPERSCHWAKE Catalogue [5]. Vehicle exploitation period is set from the date of first registration (as it can be seen from the traffic booklet) till the date when the vehicle was sold.

3.5. Disposal cost

Vehicle disposition can be as important as vehicle acquisition. The disposal procedure should start after a long use when both maintenance costs and vehicle amortization begin to grow rapidly. As this study reviews user costs, only for disposal cost is considered the sale price of a specific vehicle. Furthermore, the dismantling process is not taken into consideration.

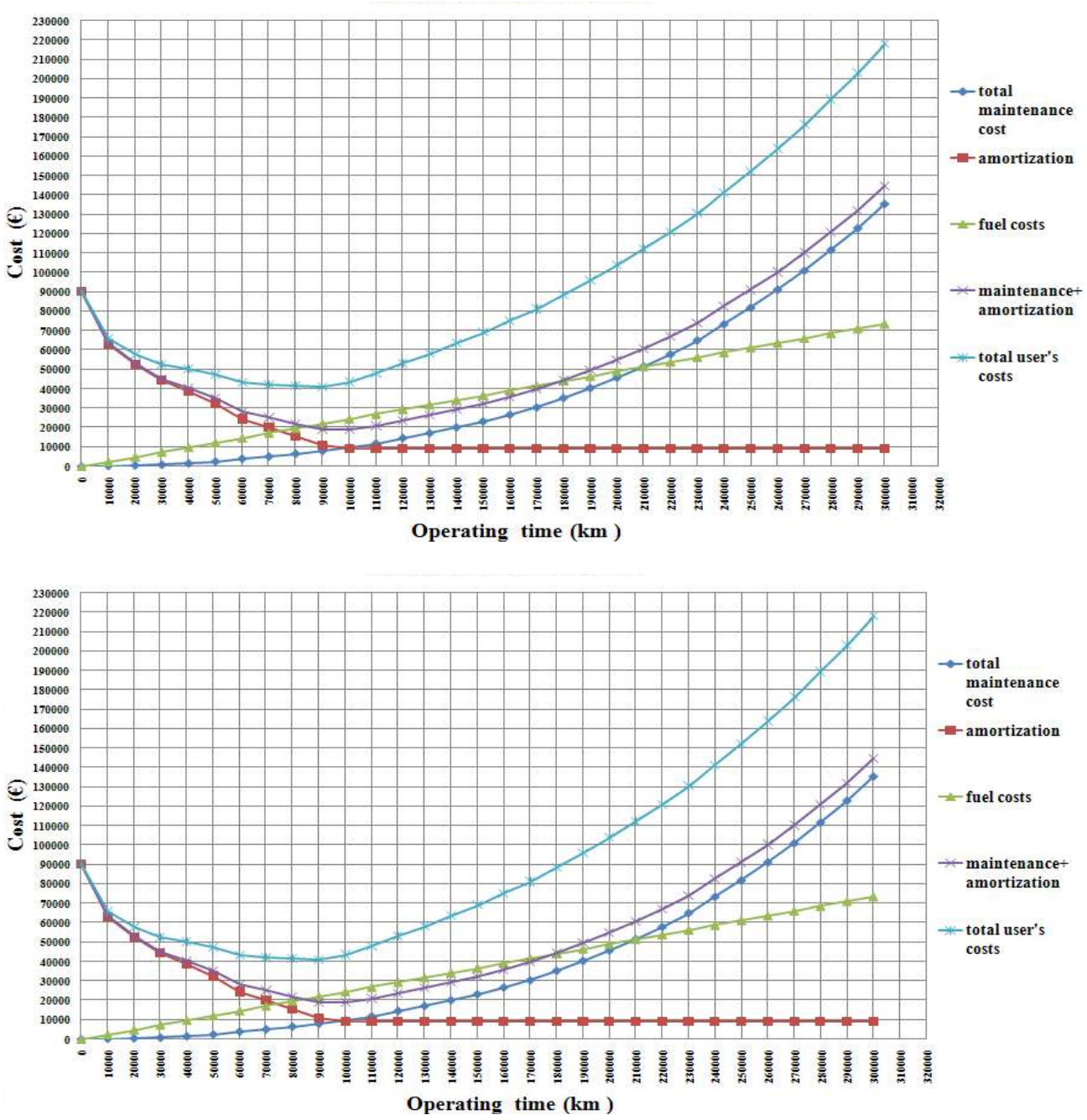

Fig. 3. IVECO CARGO user's cost for the first regime of exploitation [6]

4. CONCLUSIONS

The article describes methodology of calculating user costs on any vehicle. To carry out this task successfully, it is necessary to collect and sort data on the occurrence and relevancy of failures, costs on failures removal, preventive maintenance costs and costs on operating state. The developed LCC model on the vehicle user costs includes any influential elements found in the use of vehicles.

This model is easy to understand and allows for relevant corrections and modifications. It has been verified in this research by analyses made on the relevant military vehicles of my country.

Knowledge of the vehicle user costs may help vehicle maintenance engineers to envisage such costs for the next year and thus create their budget more successfully. Moreover, knowledge of such costs may also help vehicle manufacturers be more competitive.

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Original scientific paper

COMPARATION OF SEVERAL MODELS FOR INTERACTION IN VIRTUAL REALITY

Filip Popovski, Igor Nedelkovski

Faculty of Technical Sciences, "St Kliment Ohridski" University,
Ivo L. Ribar, 7000 Bitola, Republic of Macedonia
filip.popovski@uklo.edu.mk

A b s t r a c t: Virtual reality is the use of computer technology to create the effect of an interactive 3D world in which the objects have a sense of spatial presence. The primary difference between conventional 3D computer graphics and Virtual Reality is that in Virtual Reality we are working with things instead of pictures of things. In this paper are compared 6 models for simulation scenes in virtual reality and also is made their comparison in terms of features that they offer and the price for their implementation. The purpose of the analysis is to obtain guidance for developing own model for interactive scientific visualization adapted to circumstances in research centers in Republic of Macedonia, which means to be optimized for effective results by using cheap equipment no more than 1000 Euro.

Key words: virtual reality; virtual environments; scientific visualization; computer design; techniques of interaction

СПОРЕДБА НА НЕКОЛКУ МОДЕЛИ ЗА ИНТЕРАКЦИЈА ВО ВИРТУЕЛНА РЕАЛНОСТ

А п с т р а к т: Виртуелната реалност претставува користење на компјутерската технологија за создавање ефект на тридимензионален свет во кој предметите имаат изглед на просторна присутност. Основната разлика помеѓу конвенционалната компјутерска 3Д графика и виртуелната реалност е тоа што во виртуелната реалност работиме со предмети наместо со слики на предмети. Во овој труд се анализирани 6 модели за виртуелна реалност и направена е нивна споредба во однос на карактеристиките коишто ги нудат и цената за нивна имплементација. Целта на анализата е да се добијат насоки за развој на сопствен модел за интерактивна научна визуализација, усогласен со приликите во истражувачките центри во Република Македонија, што значи да е оптимиран за добивање ефективни резултати со користење на евтина опрема која би чинела околу 1000 EUR.

Клучни зборови: виртуелна реалност; виртуелна околина; научна визуализација; компјутерски дизајн; техники на интеракција

1. INTRODUCTION

The idea of inserting a man in some imaginary the world is very old. Needs for visualization unrealistic, but yet sufficiently realistic environments occurs in the middle of the twentieth century. First registered attempt that has similarities with modern devices was constructed by Morton Heilig (1926–1997) and was named Sensorama. It was a motorcycle simulator that had a wide range of stimuli that simulate. For visualization of images it used video projection and for sound it used appropriate audio of motorcycle. It was interesting that this device simulated vibration and even the smell of overheating tyre. In 1960 was designed the first device with built-in display that bring on the head (HMD), and in 1977's was constructed first Data Glove. The early nineties of the last century marked the development of various devices and software for virtual reality. Today, the applica-

tions for virtual reality technology provides good solutions in the implementation of complex visual requirements.

2. VIRTUAL REALITY

"Scientific visualization is the use of computer graphics to create visual images which aid in the understanding of complex, often massive numerical representations of scientific concepts or results" (McCormick, 1987).

Such numerical representations, or datasets, may be output of numerical simulations as in Computational Fluid Dynamics (CFD), Molecular Dynamics (MD) or engineering in general, sensing (recorded) data as in geological, meteorological or astrophysical applications. Visualization is essential in interpreting data for many scientific problems. It transforms numerical data into a visual representation which is much easier to understand for humans. The process of data visualization can be described as a sequence of fundamental processing steps:

- Simulation: results of numerical simulations (or data sensing / measurement) are the input of the visualization pipeline.
- Data selection & filtering: relevant regions of the raw data are selected, then filtered and enhanced. Techniques such as: i.e. enrichment & enhancement, data cropping, downsizing, noise filtering, segmentation and feature extraction can be used.
- Visualization mapping: the processed data have to be mapped / transformed into graphical primitives such as points, lines, planes / surfaces (triangle meshes), or icons, and their properties such as color, texture or opacity.
- Rendering: finally, the graphical primitives are rendered as images, which are then displayed on the screen.

Virtual reality can be defined in many ways, which all come down to the definition of a significant relationship between human and computer. It can be described as a simulation that computer graphics applies for creating a world with realistic view and that synthetic world is not static, but responds in some way to the reaction of the user and modify the environment in real time. Interactivity and its effect contributes to a strong sense of immersion – including in the environment in which is the user. He can see and manipulate with graphical objects on the screen, but also could touch and feel. Studies go in that direction to make sensors for hearing, taste and smell.

In this paper we refer to the concept of immersive Virtual Reality, which gives the user the psycho-physical experience of being present in a virtual environment consisting of interactive (virtual) objects. This experience is achieved by a proper integration of VR hardware (3D displays and spatial interaction devices) with a responsive computer-generated 3D environment.

The sensation of space and depth is essential for every VR system. The human visual system interprets the depth in sensed images using both physiological and psychophysical cues. Through the use of artificial depth cues in computer graphics, these spatial sensations can be simulated. In Immersive Virtual reality the stereo display and head tracking are used to also provide the binocular parallax and motion parallax, respectively.

Visualization in a technology of virtual reality is a graphic representation of the virtual environment in the form of images or animation and can be displayed with various output devices such as monitors, LCD projectors, TVs and similar devices that can display three-dimensional world.

3. SEVERAL MODELS FOR INTERACTION IN VIRTUAL ENVIRONMENTS

Interaction is an essential characteristic of virtual environments. Much has been published about interaction techniques in VR but the quest for truly intuitive and natural interaction techniques is still going on. Interaction between users and virtual environments is complex. Users must be able to navigate through 3D space, manipulate with virtual objects or control parameters of a simulation, and interact with the 3D GUI inside the virtual environment in a user-friendly way. In this paper are processed several models of interaction in a virtual environment and each of them has special tools and equipment.

M. Rorke, S. Bangay, P. Wentworth (2000) with the help of Rhodes University implemented the system with a magnetic tracker and simple device with four switches called virtual stick. There was worked on some problems related to interaction in immersive virtual reality and was given recommendations on how is best to deal with them. Their research showed that most applications for

virtual reality belong in the field of spatial realization and there is a very little effort to allow users to direct manipulation with objects. The main reasons for this are listed haptic force feedback, equipment for monitoring, precision of devices, etc.

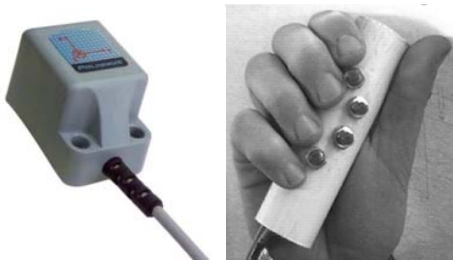


Fig. 1. Magnetic Tracker and Virtual Stick

D. Bowman (2001) proposes a systematic study of the design, evaluation and implementation of techniques of interaction in VE. He designed and effective and efficient interaction techniques in VE. Most of them belong to three categories: point of view in motion, selection and manipulation. For each of these tasks there are many proposed interaction techniques. The motion is part of a bigger task of navigation that includes real movement and decision process of the desired direction and aim of the movement. Three main components are involved in this technique and they are direction, speed and conditions which a user begins, continues and ends with the movement. Selection refers to specifying or selecting an object for a specific purpose, while manipulation refers when the user touch the objects with the virtual hand and manipulate with them. Two basic techniques of selection and manipulation are presented. The first is ray casting, while the second is arm extension. In a ray-casting technique a light ray emanates from the user's virtual hand. To select an object, the user intersects the object with the light ray and performs a "grab" action usually by pressing a button. She can then manipulate the object using the light ray. Arm-extension techniques allow the user to reach far away objects by providing a means to make the virtual arm longer than the user's physical arm. This can be accomplished by various mapping strategies, button presses, etc. The user then selects and manipulates the object as with the in-hand metaphor: touch the object with the virtual hand and manipulate it with hand movements.

M. Koutek and F. Post (2001) presented a model of spring based tool for user interaction with virtual worlds that will provide more realistic fell to the manipulation with objects in virtual environments. This tool using a spring attaches to objects and help in manipulating with them. This tool gives the user a feeling of weight or mass of the objects and can get natural visual force feedback during manipulation. When the user take some object, spring will expand proportionally to the weight of the object. Also, acceleration and deceleration of the movement will effect on the visible length of the spring.

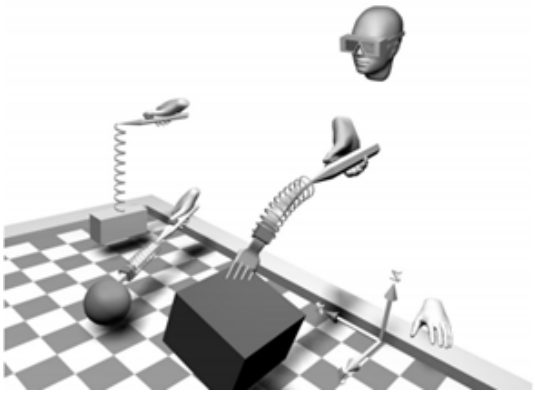


Fig. 2. Spring-based manipulation tool

J. Kjeldskov and J. Stage (2003) describe and evaluate tools for developing software applications for virtual reality. Their goal is to compare and discuss the importance of classic styles of interaction for tools that are used in development of applications for virtual reality. The focus is on the process of developing actual virtual reality applications and comparing the potential of development tools based on a command language with one tool that is based on direct manipulation. The first category can be characterized as a classical programming approach, since the creation and manipulation of the virtual world and the objects in it is specified in a command language. One of the most widely used binary libraries for developing 3D virtual worlds is CaveLib. The second category of tools for developing virtual reality applications can be characterized as a graphic representation and direct manipulation approach. One of the few professional tools in this category is dvMockup.

L. Vogelmeier and others (2006) developed an aplication for virtual reality and it was cocpit using virtual prototypes. For this aplication it is essential to ensure, that the deviation of the real human body from its virtual representation is within a defined margin. Another important feature for cockpit development is the provision of haptic feedback. Both requirements could not be satisfied using commercially available tools, so they needed to develop their own methods. In the beginning they concentrated their activities on a precise rep-

resentation of the human body. For this purpose they designed easy-to-use calibration methods for the measurement of the tracking sensor positions at the human body. In addition they developed a new kinematic model, which was able to compensate for inaccuracies, which arise from differences between the virtual and the real skeleton. In order to provide haptic feedback they built a flexible Mixed Mock-Up system, parts of which can be adjusted by the user during the VR session. For each method it is necessary to put special unit called LRU (Line Replaceable Unit). It is a box with electronics for complex engineered system that speeds up the operation.

P. Boudoin and others (2008*)* proposed a new multimodel for 3D interaction. It is a model for increasing the realness and the easiness of the interaction in virtual environment called Fly Over and is especially devoted to the navigation task. The purpose of this model is to give a sense on the user that moves naturally and easily in a virtual environment. This model offers possibility that all 3D navigation devices can be replaced with a simple pointing device called Fly Over.

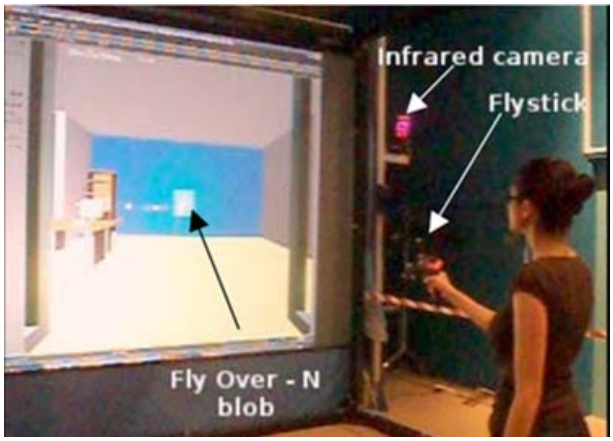


Fig. 3. Experimental setting with the use of Fly Over on the semi-immersive platform. Users navigate by moving a Flystick in their hand, which position is computed by two infrared cameras

4. ANALYSIS OF IMPLEMENTED MODELS

Model of M. Rorke is easy to use and provide tools to overcome the problems with haptic force feedback. But it also offers some alternative solutions to overcome problems in virtual environment.

In the model of D. Bowman none of the described techniques not provided optimum usability. In general Ray Casting technique is better choice than the Extended Arm technique which requires greater precision and manipulation with objects. However these techniques and research gave their contribution to the interesting and complex virtual applications such as Architectural Walkthrough and Gorilla Exhibit.

M. Koutek and F. Post designed tools to produce realistic visual force feedback. From the performed testing for manipulation in virtual environment with group of people, spring based tool is easy and intuitive to use. The results show that the behavior of the objects is a natural and predictable in most virtual environments. Synthetic models which are using the spring based tool look and feel surprisingly real. Approaximation of the mechanics seems good enough to create illusion of weight and substance.

From the performed study of J. Kjeldskov and J. Stage is showed that implementing a virtual reality application using a command language tool and a direct manipulation tool required efforts in terms of time that are comparable. The command language tool, however, resulted in faster implementation during the most essential phases of the implementation process and thus outperforms the direct manipulation tool on a larger scale. The direct manipulation tool on the other hand resulted in fewer errors. While the empirical results from the comparing shows that command language tool is simply superior to direct manipulation tool and is a three times faster in the implementation of the primary application. In further investigation direct manipulation reveals a number of more specific issues, which may have negatively influenced the performance of dvMockup.

On the model of L. Vogelmeier problem areas for examination were haptic force feedback, having a good motor skills, movement of the user and his visual perception, visual quality, etc. They made five methods for examining the interactions in the model.

The first method was to use a Data Glove for interaction in combination with a contact simulation. Visualization was provided by the data helmet and no haptic feedback was available. The contact simulation ensures that, if a collision between the LRU and the aircraft structure occurs, a compensation movement is calculated. If a collision occurs and the real hand continues to move, the positions of the real hand and the virtual hand do no longer correspond. This positional difference is visualized by the introduction of a second virtual hand in a

wireframe look which represents the position of the real hand.

Fig. 4. Holding a Ball with Two Virtual Hands; the Opaque Hands Show the Positions of the Virtual Hands, the Wireframe Hands Show the Positions of the User's Real Hands. They are, in contrast to the virtual hands, able to penetrate the ball.

The second option was to skip the contact simulation and to utilise a real size model of the LRU made of polystyrene. It was provided with an additional tracking sensor, so that the movement of the real LRU and its virtual representation matched. The user was wearing two datagloves, they were visualized by two virtual hands. So the user was able to see and also feel the LRU.

The third method applied an active force feedback device (FFD), which comprises a robotic arm, the joints of which were controlled by electric motors. The FFD allowed to provide a force on to the user. The range of the robotic arm was comparable to the range of a human arm. A mock-up of the LRU was mounted at the end of the FFD arm. The contact simulation linked to the FFD made sure that, in case of a collision between LRU and aircraft structure, the respective force is transmitted to the user.

Fig. 5. User Working with the Force Feedback Device

The fourth interaction method was to use a Space Mouse to control the movement of the LRU in combination with a contact simulation. The visualization was stereoscopic on a desktop monitor. The Space Mouse allowed the user to move an object in all six degrees of freedom.

Fig. 6. Space MouseTable Captions

The last method was to use a Flying Mouse for the control of the movement of the LRU in combination with a contact simulation. The visualization was done in a four Side Cave System. The Flying Mouse has the form of a handle; it contains one or more triggers and a tracking sensor to pick up its position and orientation in space. By pressing a trigger, the virtual LRU is tied to the Flying Mouse and is moved according to the movement of the Flying Mouse. With the Flying Mouse it was much easier to control the LRU than with the SpaceMouse.

Fig. 7. Flying Mouse

Model of P. Boudoin is based on two main ideas. First, all basic 3D interaction tasks may be

turned into a simple pointing task. Second, the 6D space of the user (3D position and 3D orientation) may be seen as a set of hyperspaces in which a separate pointing task may be applied. Due to these ideas, Fly Over may be utilized the same way with various 2D, 3D or 6D devices. The generic model has been applied to a 2D navigation task and has been compared to the gaze-steering technique. Preliminary qualitative results shows that Fly Over generates smoother trajectories and is well accepted by the users.

5. COMPARATION

Overview of the characteristics of processed modes is shown in Table 1, while the cost of each individual model are shown in Table 2.

Table 1

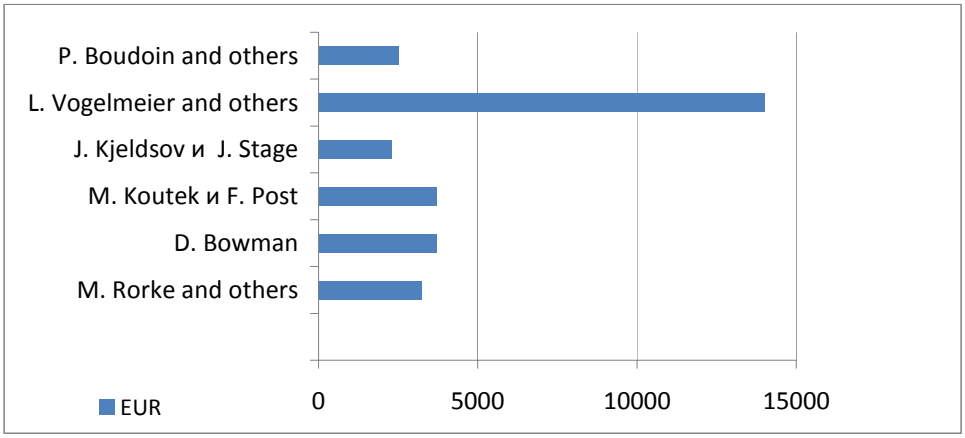
Overview of the characteristics of the considered models

Author	Dim	FF	Using			Looking to			TA
			HMD	VH	VS	VD	CV	CK	
M. Rorke and others	3D	–	X	–	X	X	–	–	10 min.
D. Bowman	3D	–	X	X	–	X	–	–	1 hour
M. Koutek and F. Post	3D	X	X	X	–	X	–	–	3–8 hours
J. Kjeldskov and J. Stage	3D	–	–	–	–	X	–	–	2–10 hours
L. Vogelmeier and others	3D	X	X	X	X	X	X	X	24–72 hours
P. Boudoin and others	3D	–	–	–	X	X	–	–	1 hour

Legend:
Dim – Dimensions, VD – Virtual Display, FF – Force Feedback, CV – CAVE, HMD – Head Mounted Diplay, CK – Cockpit for Virtual Reality, VH – Virtual Hands, TA – Time of Adjustment, VS – Virtual Stick, X – yes / no

Table 2

Overview of costs



6. CONCLUSIONS

From the performed comparation all models related to 3D virtual environment. Also, in each of these models user view is directed to the virtual display or virtual workbench, with the exception of the model of L. Vogelmeier which included also cockpit for virtual reality. In most models is used HMD and equipment appropriate for each model. But an important characteristic is that only two models had force feedback in contact with objects in the virtual environment. Another important ele-

ment in these models is a time of adaptation by the user. From performed analysis model of M. Rorke is the easiest for using and can be used after 10 minutes of exercise. All models have a similar price in the market which is around 3000 EUR excluding model of L. Vogelmeier which is very expensive due to the complexity of the system and the high performance it has.

At te Faculty of Technical Sciences in Bitola in progress is development a model for interactive scientific visualization that will be based on the following principles:

- user friendly interface;
- using open soure libraries;
- using computer monitor or LED TV;
- unexpensive accessories needed for virtual navigation (HMD, trackball, virtual stick).

The same model compared with analyzed is expected to have the following advantages:

- to enable work on any computer that supports CAD software who can run interactive scientific visualization;
- it will be a low cost about 1,000 EUR;
- it will give a contribution to the field of interactive scientific visualization as a tool for a large number of users which are not specialized in the field of engineering technology and virtual reality.

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COMPARISON OF SIMULATED AND MEASURED RESPONSE OF LOAD REJECTION ON A HYDRO POWER PLANT MODEL WITH MIXED MODE NONLINEAR CONTROLLER

Darko Babunski, Atanasko Tuneski, Emil Zaev

"Ss. Cyril and Methodius" University in Skopje, Faculty of Mechanical Engineering,
Karpoš II bb, P.O. box 464, 1001 Skopje, Republic of Macedonia,
darko.babunski@mf.edu.mk

A b s t r a c t: Revised Hydro Power Plant model of the IEEE working group recommended converted to state space model is used for simulation of transient response of hydro turbine, and verification was made using measurements of transients from real Hydro Power Plant (HPP). Nonlinear mixed model controller was designed and implemented into complete HPP simulation model and compared with PID with real parameters used in HPP, and with adjusted PID parameters with consideration of smallest frequency error. Verification of performance of the model was made comparing model response with measured load rejection, which is worst case of HPP operation.

Key words: hydro power plant; hydro turbine; nonlinear control; controller

СПОРЕДБА НА СИМУЛИРАН И ИЗМЕРЕН ОДЗИВ ПРИ ОДБИВАЊЕ НА ОПТОВАРУВАЊЕ НА МОДЕЛ НА ХИДРОЕЛЕКТРИЧНА ПОСТРОЈКА СО КОМБИНИРАН НЕЛИНЕАРЕН УПРАВУВАЧ

А п с т р а к т: За симулација на однесувањето на хидроелектричните постројки (ХЕП) во екстремни ситуации како што се побег, одбивање на оптоварување и слично, се користи ревидираниот модел на работната група на IEEE, приведен во простор на состојба и верифициран преку експериментални мерења на преодните карактеристики на ХЕП. Проектиран е нов комбиниран нелинеарен управувач и е имплементиран во верифицираниот модел на ХЕП. Одзивите на така дефинираниот систем се споредени со реално измерените одзиви на ХЕП, како и со симулации на модели на ХЕП кои користат два типа на ПИД-управување

Клучни зборови: хидроенергетска постројка; хидраулична турбина; нелинеарно управување; управувач

1. INTRODUCTION

Hydro Turbine is highly nonlinear device which behavior is highly unpredictable and varying with change of network load. Because of that, use of linearized models for simulation of dynamic response characteristics of Hydro Turbine is not recommended. In this paper revised model of the IEEE working group [1] recommended is used for simulation of transient response of hydro turbine, and verification was made using measurements of transients from real Hydro Power Plant (HPP). After that, nonlinear mixed model controller was designed and implemented into complete HPP simulation model. Verification of performance of the model was made comparing model response with measured load rejection, which is worst case of HPP operation. Simulation response was compared to simulation model with PID with real parameters used in HPP, and with adjusted PID parameters with consideration of smallest frequency error.

2. NONLINEAR HYDRO POWER PLANT MODEL WITH SURGE TANK

Recommended models for simulation of hydro turbine [1, 2] are mainly nonlinear models for hydro turbine with tunnel, surge tank and penstock,

with or without implementing elastic properties of the water column above turbine, and penstock material. In this paper, comparative analysis of the response characteristics of models of hydro turbine with measured dynamic characteristics of the real HPP with medium head and short penstock (Tw < 3 seconds) was made. Comparison of the results shows that the influence of the surge tank and elastic properties of the water column and penstock material is minor for HPP with medium head and short penstock [3]. Because of that control law was designed for model with surge tank and without elastic properties, shown on Figure 1.

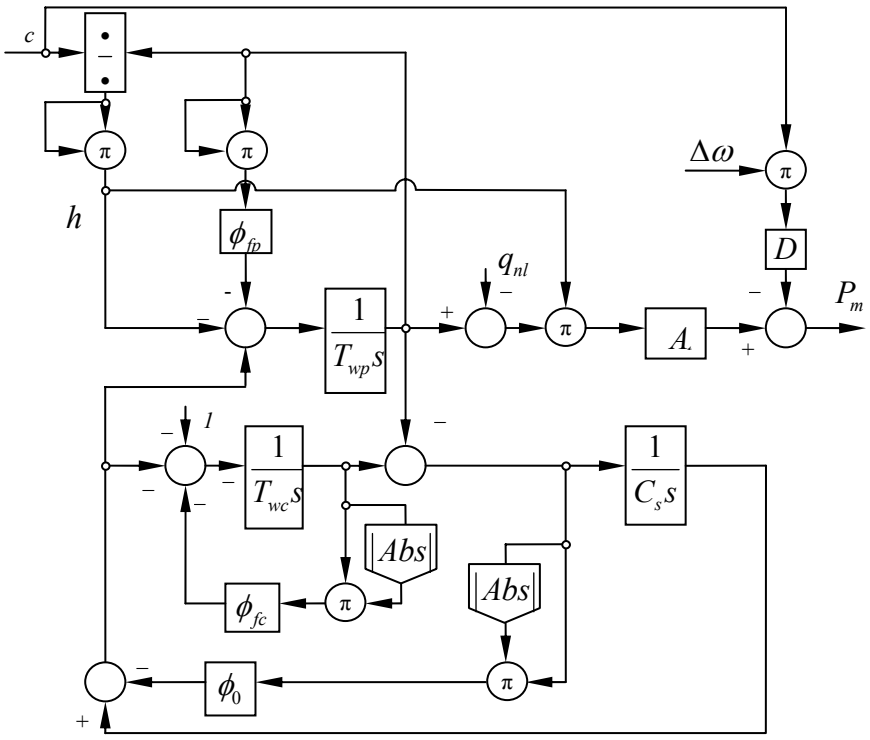

Fig. 1. Nonlinear hydro turbine model

General nonlinear equations that describe Hydro Power Plant model are:

Dynamics of the common conduit before surge tank:

$$h_s = h_0 - h_{fc} - h_{qc} \text{ (pu)} \tag{1}$$

$$h_{fc} = \phi_{fc} q_c \left[q_c \right] \text{ (pu)} \tag{2}$$

$$h_{qc} = T_{wc} \frac{dq_c}{dt} \text{ (pu)} \tag{3}$$

Dynamics of the surge tank:

$$h_s = \frac{1}{C_s} \int q_s dt - \varphi_0 q_s [q_s] \text{ (pu)} \tag{4}$$

where

$$C_s = \frac{A_s h_{\text{base}}}{q_{\text{base}}} \text{ (s)}, \qquad q_c = q_p + q_s \text{ (pu)} \tag{5}$$

Dynamics of the pressure penstock:

$$h_t = h_s - h_{fp} - h_{qp} \text{ (pu)} \tag{6}$$

$$h_{fp} = \varphi_{fp} q_p^2 \text{ (pu)} \tag{7}$$

$$h_{qp} = T_{wp} \frac{dqlp}{dt} \text{ (pu)} \tag{8}$$

where $T_w = \frac{Lq_{base}}{Agh_{base}}$ (s) is water starting time,

water flow through hydro turbine is:

$$q_t = c\sqrt{h_t} \tag{9}$$

and the mechanical power produced with hydro turbine is:

$$P_m = Ah\left(q - q_{nl}\right) - Dc\Delta\omega \,. \tag{10}$$

For the task of design of nonlinear control law model of Hydro Power Plant should be converted

into state space model representation defined with following general nonlinear equation:

$$\dot{x} = f(x) + G(x)u \qquad y = h(x) \tag{11}$$

State variables are defined with following equations: $x_1 = q_t$, $x_2 = h_s$, $x_3 = q_c$ и $x_4 = c$ and combining above equations lead to following representation of the HPP model in state space:

$$f(x) = \begin{bmatrix} \frac{1}{T_{wp}}\left(x_2 - \left(\phi_{fp} + \frac{1}{x_4^2}\right)x_1^2\right) \\ \frac{x_3 - x_1}{C_s} \\ \frac{1}{T_{ws}}\left(h_o - x_2 - \phi_{fc} x_3 [x_3]\right) \\ -\frac{x_4}{T_g} \end{bmatrix} \tag{12}$$

$$g(x) = \begin{bmatrix} 0 \\ 0 \\ 0 \\ \frac{1}{T_g} \end{bmatrix} \tag{13}$$

$$h(x) = x_4 . \tag{14}$$

3. DESIGN OF NONLINEAR MIXED MODE CONTROL

Nonlinear controller was designed using partial state linearization method, simulation model was integrated and simulation results of load rejection were compared with PID and gain scheduling controller simulation results and with measurement of the load rejection on the real HPP.

The procedure of designing the nonlinear controller is following: for nonlinear system defined with (12), (13) and (14) exist local diffeomorphism $z = \Phi(x)$ with $\Phi(0) = 0$, for which system in z coordinate system become:

$$\begin{bmatrix} \dot{z}_1 \\ \dot{z}_2 \\ \dot{z}_3 \\ \dot{z}_4 \end{bmatrix} = \begin{bmatrix} L_f \varphi_1(x) \\ L_f \varphi_2(x) \\ L_f \varphi_3(x) \\ L_f \varphi_4(x) + \mathrm{u} \end{bmatrix} \tag{15}$$

After transformation with:

$$u = -L_f \varphi_4(x) + v \tag{16}$$

equation (15) will have this form:

$$\begin{bmatrix} \dot{z}_1 \\ \dot{z}_2 \\ \dot{z}_3 \\ \dot{z}_4 \end{bmatrix} = \begin{bmatrix} L_f \varphi_1(x) \\ L_f \varphi_2(x) \\ L_f \varphi_3(x) \\ v \end{bmatrix} \tag{17}$$

Above system has relative degree $r = 1$ and the system is partially linearizable with stabilizing controller in feedback.

In this case local diffeomorphism will become:

$$\begin{bmatrix} z_1 \\ z_2 \\ z_3 \\ z_4 \end{bmatrix} = \begin{bmatrix} \varphi_1(x) \\ \varphi_2(x) \\ \varphi_3(x) \\ \varphi_4(x) \end{bmatrix} = \begin{bmatrix} x_1 \\ x_2 \\ x_3 \\ T_g x_4 \end{bmatrix} \tag{18}$$

and the control variable becomes:

$$u = -L_f \varphi_4(x) + v = x_4 + v \tag{19}$$

Nonlinear control law (19) is used in parallel with conventional PI controller and thus became mixed mode nonlinear controller. Introduction of feedback controller causes partial linearization of the state vector, splitting dynamics of the system to external linear part and internal nonlinear and non-observable part. Integrated model and nonlinear controller is shown on Figure 2.

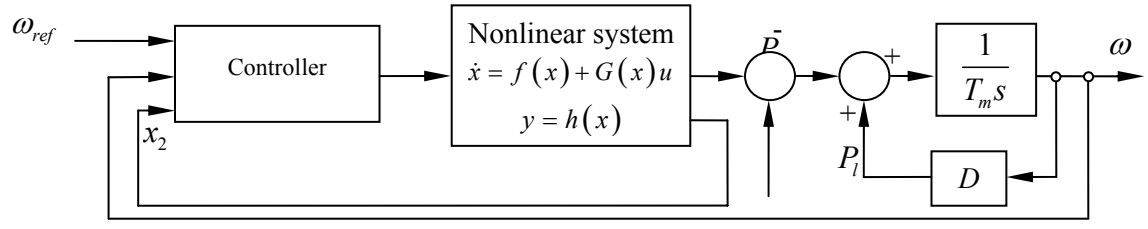

Fig. 2. Integrated Hydro Power Plant model

Designed control law asymptotically stabilizes the system around working point because vector field of zero dynamics of the system is also asymptotically stable.

4. COMPARISON BETWEEN SIMULATED AND MEASURED RESULTS

Verification of performance of the model was made comparing model response with measured load rejection, which is worst case of HPP operation.

Parameters of the HPP model used for simulation are given in Tables 1 and 2.

Response of simulation models is shown on Figure 3.

Table 1

Parameters of HPP

Turbine power	41 MW
Base flow	50 m^3/s
Base head	92 m
Water starting time T_w	1,434 s
Head loss coefficient k_f	0,001071 $m/(m^3/s)^2$
Turbine gain A_t	1,1211
No load flow q_{nl}	0.08 pu
Surge tank constant C_s	36,11 s

Table 2

Parameters of used controllers

Controller	*Kp*	*Ki*	*Kd*
PID	2	0.465	1.06
Nonlinear mixed	5	20	–

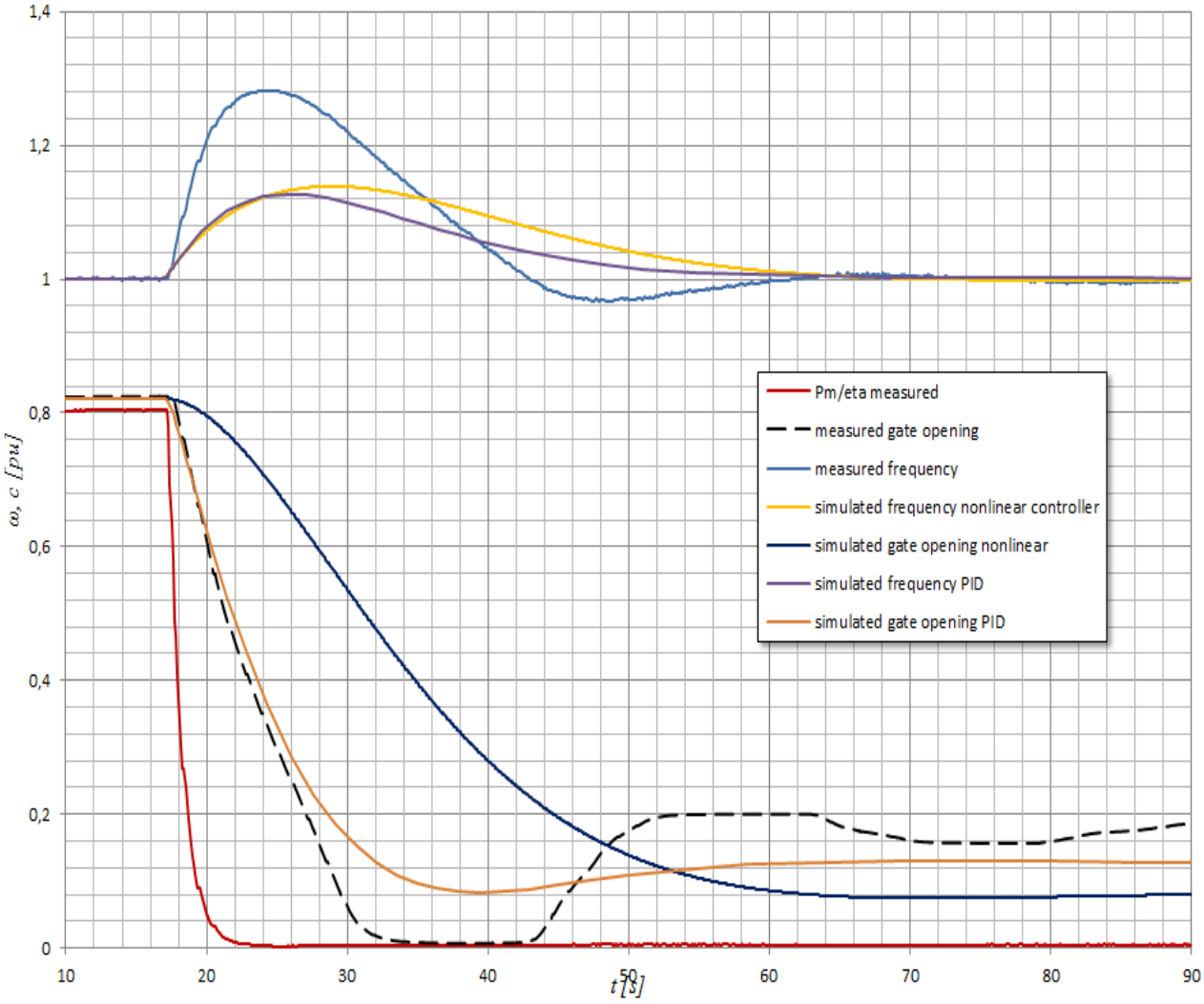

Fig. 3. Simulation of load rejection

5. CONCLUSIONS

Comparisons of simulation and measured results show that nonlinear controller have robust response, increased gain and phase margin in comparison with linear control laws, although all control laws have satisfactory response for load rejection on modeled HPP. General conclusion is that for HPP with medium head and short penstock, where effects of surge tank and elastic characteristics are minor, careful adjustment of controller parameters is of greater importance that used control law, although nonlinear control law show more robust and slower response with large load change.

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Original scientific paper

ADVANCED EVACUATION MODEL MANAGED THROUGH FUZZY LOGIC DURING AN ACCIDENT IN LNG TERMINAL

Goran Stanković, Stojan Petelin, Marko Perkovič, Peter Vidmar

Faculty for Maritime Studies and Transport, University of Ljubljana,
Pot pomorščakov 4, 6320 Portorož, Republic of Slovenia
gstankovicg@yahoo.com

A b s t r a c t: Evacuation of people located inside the enclosed area of an LNG terminal is a complex problem, especially considering that accidents involving LNG are potentially very hazardous. In order to create an evacuation model managed through fuzzy logic, extensive influence must be generated from safety analyses. A very important moment in the optimal functioning of an evacuation model is the creation of a database which incorporates all input indicators. The output result is the creation of a safety evacuation route which is active at the moment of the accident.

Key words: evacuation model; risk analysis; fuzzy logic; LNG terminal

НАПРЕДЕН ЕВАКУАЦИОНЕН МОДЕЛ УПРАВУВАН ПРЕКУ FUZZY-ЛОГИКА ПРИ НЕЗГОДА ВО ТЕРМИНАЛ ЗА ТЕЧЕН ПРИРОДЕН ГАС

А п с т р а к т: Евакуацијата на луѓето кои се наоѓаат внатре во ограден простор од терминал за течен природен гас (ТПГ) претставува комплексен проблем имајќи предвид дека незгодите со ТПГ се потенцијално многу опасни. За да се изработи евакуационен модел управуван преку Fuzzy-логика, големо влијание имаат спроведените безбедносни анализи. За оптимално функционирање на евакуациониот модел од голема важност е креирањето на база на податоци која ќе ги содржи сите влезни податоци. Краен излезен резултат е креирање на безбедна евакуациона рута која е активна во моментот на незгодата.

Клучни зборови: евакуационен модел; безбедносни анализи; fuzzy-логика; терминал за ТПГ

1. INTRODUCTION

Due to the ever increasing call for energy in the world, there is more and more need to use natural gas as an energy source and hence the need to open new Liquid Natural Gas (LNG) terminals as shipment by sea is inevitable. Basic information regarding LNG terminals is the capacity and number of LNG storage tanks as well as the size and the capacity of the tankers which carry out the transport to the terminal. The potential hazard associated with LNG mainly comes from the possibility of an accident with consequences generated by LNG leakage. In such situations, a very possible occurrence is fire and thermal radiation. If the events lead to leakage of a greater quantity of LNG – into a pool - a cloud is created due to the evaporation which contains natural gas, water, steam and air. Due to its weight, the cloud, being heavier than the air, remains at the surface of the earth. The evaporated natural gas may be significantly influenced by the atmospheric conditions and the geographic-topographic features of the terrain. The cloud shifts according to the direction of the wind, while the speed of the wind additionally effects the mixing of the natural gas with the air. This mixture is flammable when the concentration of the natural gas in the air ranges between 5% and 15%. The dispersion of the cloud represents a danger to people, which is increased in the case of flammability. The rapid evacuation of people in such a situation is essential.

Fuzzy logic, as a part of an artificial intelligence computational method, is being increasingly used during different industrial researches, above all for the purpose of advancing the process of decision making, the combined predictions, probability theories and similar, in situations where the existing data are insufficiently accurate or insufficiently precise. An extensive number of the route planning models use the fuzzy logic with the objective to obtain precise data which influence during the selection of the best route for individuals or group of people.

The risk for employees at the LNG terminal is greatest. The lack of advanced evacuations in situations of LNG leakage accidents indicates a need for designing evacuation models which apply to those both inside and outside the enclosed part of the LNG terminal.

2. GENERAL DESCRIPTION OF THE EVACUATION MODEL

This paper describes an evacuation model intended for the people located inside the LNG terminal. Risk analysis techniques are divided into four categories: deterministic, probabilistic, qualitative and quantitative. During the risk analysis, several methods can be used: Event and Fault three analysis, Hazard and Operability analysis (HAZOP), Hazard Identification (HAZID), Quantitative risk assessment (QRA), Layer of protection analysis (LOPA), and Probabilistic risk assessment. The model uses data generated by conducting Quantitative risk assessment (QRA) [1][2] of events involved in LNG leakage accidents. The management or the control of the evacuation model is performed using FUZZY LOGIC [3], where the final output result is crucial during the selection of the shortest safe evacuation route for each individual located in the LNG terminal.

Quantitative risk assessment

The objective of conducting the QRA is to identify the potential impact of the LNG leakage accident on the workers in the terminal. The analyses result in a time-based and spatial presentation of the dispersion of the evaporated LNG, its concentration in the air, as well as thermal radiation. For more precise management of the evacuation, the area of the terminal is divided into cells (smaller blocks), as shown in Figure 1.

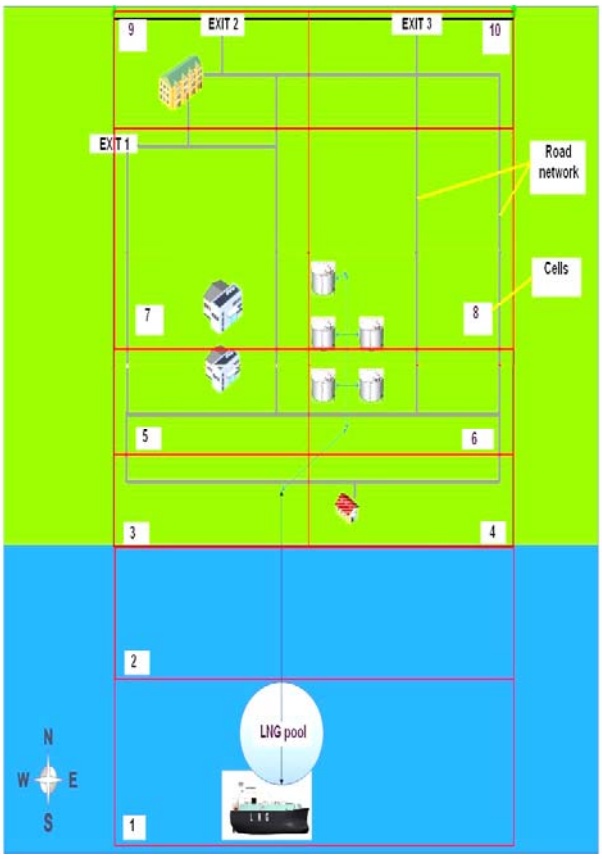

Fig. 1. Scheme of the modelled LNG terminal

The areas which are a potential source of an LNG leakage accident are identified well in advance, including the maximum quantity of LNG that may leak. For each cell or area, the consequence from the accident is separately defined (possible size of a crack as a consequence of the accident, maximum quantity of the leaked LNG, the size of the leaked LNG, the area in which the LNG is leaking and so on) and in compliance with these data and other input parameters, the QRA is carried out. Potential accidents with LNG leakage involve cryogenic pipeline systems which are used to transport LNG, storage tanks, mooring LNG tankers during off-loading in storage tanks and so on. Intentional threats may range from insider threats to intentional external attacks. During such events, there is a small chance of complete leakage of LNG from each tank separately, but with the objective to obtain conservative calculations of the dimensions of an accident, we shall presuppose that the tanks have been completely emptied. In compliance with the described LNG terminal, we may distinguish several scenarios. Scenario 1 refers to an accident with a moored LNG tanker under the process of off-loading (cell 1), Scenario 2 refers to an accident with the pipeline system in the

process of off-loading (cells 2 and 4), Scenario 3 refers to an accident with the LNG storage tanks (cells 6 and 8) and Scenario 4 refers to an accident in the re-gasification plant.

In this case, we will review the example of an accident that occurs when mooring an LNG tanker during the course of off-loading (Scenario 1). The accidents caused by terrorist attacks are scenarios considered to have the biggest negative impact. It has been estimated that in such cases, there is a possibility of a maximal crack in the tanker of 1500 mm [4], creating conditions for a pool with a diameter of up to 400 m [4 – 7]. Scenario 1 thus includes a crack of 1500 mm and an LNG pool with a diameter of 400m. The behaviour of the evaporated natural gas from the LNG pool may be calculated by using a Fire Dynamics Simulator (FDS) on the basis of Computational Fluid Dynamics (CFD) modelling of the dispersion of the natural gas into the surrounding environment [8 – 12]. The speed and the direction of the wind, as well as the atmospheric class, plays an immense role when it comes to the length, speed, direction and the time frame of the dispersion of the evaporated natural gas, as well as the flammable concentration of the mixture of natural gas and air. Additionally, in case of fire, one can calculate the quantity of thermal radiation to the surrounding environment, consequently allowing the presentation of this in a spatial and time sense [13, 14]. The scenarios will be conducted using the created 3D model of an LNG Terminal for which the evacuation model will be made. The Scenario 1 simulates the evaporation of natural gas from the LNG pool on a water surface with a size of 160 000 m^2 (400×400m). The dimensions of the presented model are 3000 m per x axis, 3000 m per y axis and 300 m per z axis. The atmospheric wind has a speed of 2 m/s and disperses the gas cloud in the direction of the wind. The temperature of the sea water is set to 20 °C. The simulation of the dispersion is calculated with the use of the FDS program [15]. Additional obstacles are considered (vessel, buildings, storage tanks...) which might have an influence on the spreading gas.

Figures 2 and 3 show examples of the length of the dispersion with concentration of methane in the air between 5% and 15% depending on the time of the leaked LNG from the moored tanker.

Through the calculated data from the analyses, we identify the cell, time and magnitude of the danger for the people at the terminal. All of these data should be incorporated into the database. The objective of the database is to understand the influences of the accident, and for creating the rules and procedures under which the evacuation model will be managed with the use of fuzzy logic. For a better evacuation model, it is necessary to perform as much as possible analyses with different input parameters for the speed and the direction of the wind, temperature data, location of the leakage, the type of the area/surface where the LNG is leaking and the like. Some scenarios can be excluded, since they do not pose a threat to the terminal. With this approach we achieve a simplification and reduce the time and efforts required for completing our database. Due to this, according to the Scenario 1, the directions of the wind North (N) (Table 1.1), Northeast (NE) (Table 1.2) and Northwest (NW) (Table 1.3) only will be included.

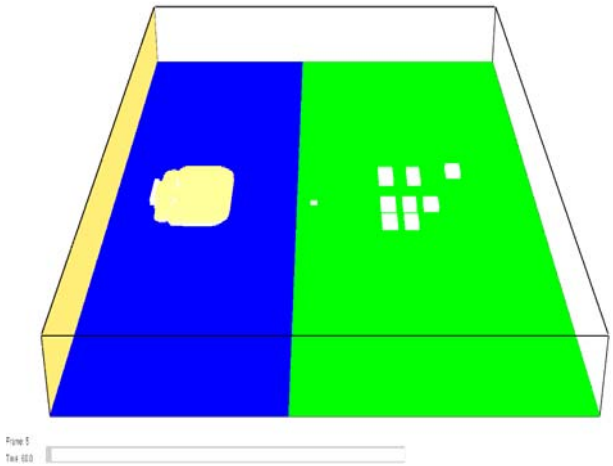

Fig. 2. Dispersion of the LNG vapour after 60 seconds

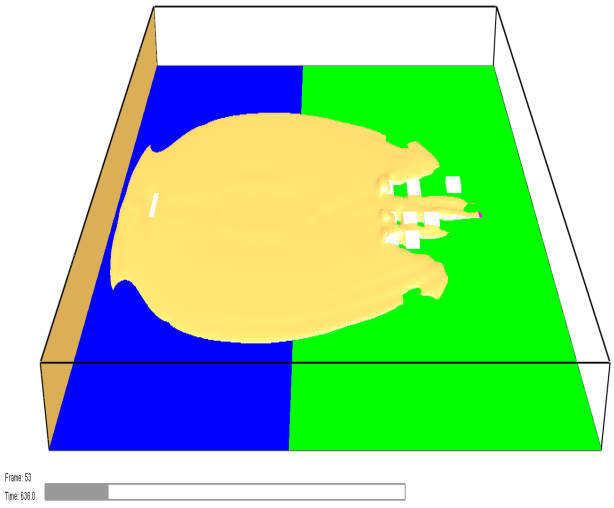

Fig. 3. Dispersion of LNG vapour after 636 seconds

Table 1.1

Time data per accident, length of dispersion, risk and safe cells and exits

Scenario 1, D(pool) = 400 m, off-loading LNG tanker Wind direction N, V = 2 m/s			
Time (s)	Dispersion (m)	Risk cells	Safe cells and exits
.	.	.	.
100	600	1,2	3 – 10 / exits 1,2,3
.	.	.	.
170	880	1,2	3 – 10 / exits 1,2,3
200	1000	1,2,3,4	5 – 10 / exits 1,2,3
230	1150	1,2,3,4	5 – 10 / exits 1,2,3
.	.	.	.
320	1450	1,2,3,4,5,6	7 – 10 / exits 1,2,3
.	.	.	.
370	1600	1,2,3,4,5,6	7 – 10 / exits 1,2,3
.	.	.	.
430	1740	1,2,3,4,5,6,7,8	9 – 10 / exits 2,3
.	.	.	.
500	2020	1,2,3,4,5,6,7,8	9 – 10 / exits 2,3
540	2100	1 – 10	/
.	.	.	.
1070	2070	1 – 10	/
.	.	.	.
1130	>3000	1 – 10	/

Table 1.2

Time data per accident, length of dispersion, risk and safe cells and exits

Scenario 1, D(pool) = 400 m, off-loading LNG tanker Wind direction NE, V = 2 m/s			
Time (s)	Dispersion (m)	Risk cells	Safe cells and exits
.	.	.	.
100	610	1,2	3 – 10 / exits 1,2,3
.	.	.	.
170	890	1,2	3 – 10 / exits 1,2,3
200	1005	1,2,3,4	5 – 10 / exits 1,2,3
230	1140	1,2,3,4	5 – 10 / exits 1,2,3
.	.	.	.
320	1430	1,2,3,4,5,6	7 – 10 / exits 1,2,3
.	.	.	.
370	1590	1,2,3,4,6	5,7 – 10 / exits 1,2,3
.	.	.	.
430	1750	1,2,3,4,5,6,8	7,9,10 / exits 1,2,3
.	.	.	.
500	2010	1,2,3,4,5,6,8,10	7,9 / exits 1,2
540	2090	1,2,3,4,5,6,7,8,10	9 / exit 2
.	.	.	.
1070	2800	1 – 10	/
.	.	.	.
1130	>3000	1 – 10	//

Table 1.3

Time data per accident, length of dispersion, risk and safe cells and exits

Scenario 1, D(pool) = 400 m, off-loading LNG tanker Wind direction NW, V = 2 m/s			
Time (s)	Dispersion (m)	Risk cells	Safe cells and exits
.	.	.	.
100	610	1,2	3 – 10 / exits 1,2,3
.	.	.	.
170	890	1,2	3 – 10 / exits 1,2,3
200	1005	1,2,3,4	5 – 10 / exits 1,2,3
230	1140	1,2,3,4	5 – 10 / exits 1,2,3
.	.	.	.
320	1430	1,2,3,4,5,6	7 – 10 / exits 1,2,3
.	.	.	.
370	1590	1,2,3,4,5	6,7 – 10 / exits 1,2,3
.	.	.	.
430	1750	1,2,3,4,5,6,7	8,9,10 / exits 2,3
.	.	.	.
500	2020	1,2,3,4,5,6,7,8	9,10 / exits 2,3
540	2090	1,2,3,4,5,6,7,8,9	10 / exit 3
.	.	.	.
1070	2800	1 – 10	/
.	.	.	.
1130	>3000	1 – 10	/

Evacuation model managed / controlled via fuzzy logic

Evacuations happen frequently. People are evacuated from their homes, businesses, ships, and more, in response to actual or predicted threats of hazards such as hurricanes, floods, tsunamis, volcanic eruption, and release of hazardous or nuclear materials, fires and explosions [16]. Evacuation is a way of increasing the distance between the population and a hazard, and is the counter measure to toxic chemical releases with which there is the most experience. The term evacuation also describes the withdrawal of persons from a specific area because of a real or anticipated threat or hazard.

In the last decade the warning process and response, organizational response, behaviour in evacuations, evacuation planning and management has been more in focus than had been the case in the past. The stress has been on the quality of information, the timing of message delivery and compliance with warnings. The new warning technologies include cell phones, the internet, Global Positioning System (GPS) devices, etc. Each individual in the LNG terminal, after being alerted to an accident through with alarm systems, is in a

dilemma regarding the best evacuation route to choose. The slightest probability of risk given any chosen route implies potential fatality. The larger the scale of an accident is, the greater the probability of an individual making an error in choosing a route. Having said this, there is a need for the development of an evacuation model which is to be managed using fuzzy logic and is meant to relocate individuals via safe routes as well as via safe areas which are not endangered by the accident. The on-time evacuation of people is of essential significance for the decrease of risk; i.e. minimizing the human consequences of an accident event. The data from a database produced through the carried out QRA, provides a clear picture of which cells of the terminal at which time after the recognition of the accident will be at a particular risk. In addition, by using those data, precise dimensioning of the fuzzy sets is being performed. It also provides images of the optimal evacuation routes at given times after the accident. Of great importance is the early detection of the accident. The devices for detecting gas or heat indicate the location where the LNG leakage accident happened [17]. This is the starting point for the creation of one dynamic evacuation model. As we have mentioned, all locations have been pre-evaluated in terms of potential leakage as well as the maximum quantities of leaked LNG. The location of the detected accident and direction of the wind, the speed of the wind, the atmospheric temperature and the temperature and the type of the surface where the accident takes place are the input parameters which indicate the selection of the scenario (Figure 4) by which the dynamic evacuation routes for the individuals are created. For each cell of the terminal in compliance with the selected scenario, via the QRA, the program will provide insight into the time such a cell will be affected. Also, the safe-havens or shelters which are foreseen in case of an accident are also emphasized. In the end we determine which parts of the travel route at what time are safe for use during a dynamic evacuation. For a successful execution of the evacuation, a GPS device with an installed map, streets and routes and shelters of the LNG terminal which people can use is required. The device provides the accurate location of the individual at the time of the occurrence of the accident. With this, the individual represents the starting point A used to create his/her safety evacuation route. The evacuation route directs the individual to the end point B, which is at a location that will not be affected by the accident, and is obtained from the carried out analyses [7]. The evacuation management device, for a specifically determined short time interval, depending on the location of the individual identified via the GPS device, refreshes the analysis for creating a safe evacuation route, which in case of change in the initially shown route will alert the evacuee to any change, projecting the newly created evacuation route.

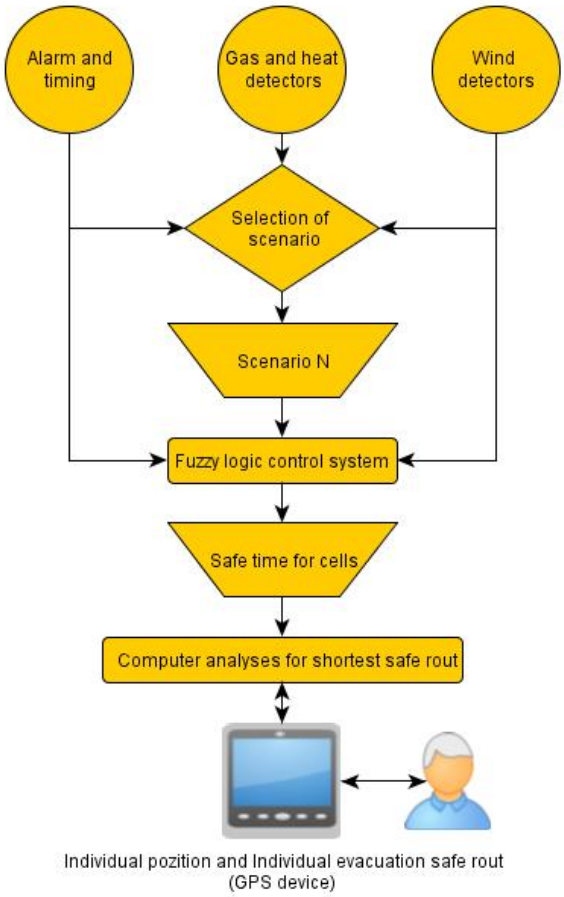

Fig. 4. Selection of Scenario

Fuzzy logic modelling approach for control/management of the evacuation model

The fuzzy logic tool provides a technique which allows us to deal with the imprecision and uncertainty of the information [18]. The modelling of the large spills of LNG is a complex process which realistically is very difficult to execute. The largest part of the data which portray the large scale accidents are generated through sophisticated computer programs. The noticeable variance of the results generated from different computer programs but with the same input parameters, leads us to a situation of having certain doubts in terms of the obtained data. One of the advantages of fuzzy logic is dealing with the problems when the data are imprecise and uncertain.

The basic elements of any given fuzzy logic system [3, 19, 20] are: rules, fuzzifier, inference engine, and defuzzifier (Figure 5). The main task of the fuzzifier is converting fuzzy variables into crisp number and mapping them into fuzzy sets. The task of inference engine is mapping of input fuzzy sets into fuzzy output sets by using knowledge base rules. This procedure is followed by IF-THEN rules, established on the basis of human knowledge or mathematical calculation. The main task of the defuzzifier is opposite of fuzzifier and reaches to a precise and deffuzified output for any variable.

During the design of the fuzzy logic systems, one defines the input and output variables, identifies the membership functions and creates the database of fuzzy variables. There is a distinction between linguistic and numeric data – i.e., information. The linguistic data usually express a certain experience through words, while the numeric data in reference to a specific phenomenon are generated on the basis of measurements, experiments and statistical analyses. In our case, the QRA provide us with both linguistic and numeric data, on the basis of which the input and output variables are created, including the set of fuzzy rules. The basic task of fuzzy logic for management of the evacuation model is to make the proper selection of a route for evacuation for each individual in the terminal, which eliminates the possibility of an error during the selection of an evacuation route when such is created by an individual.

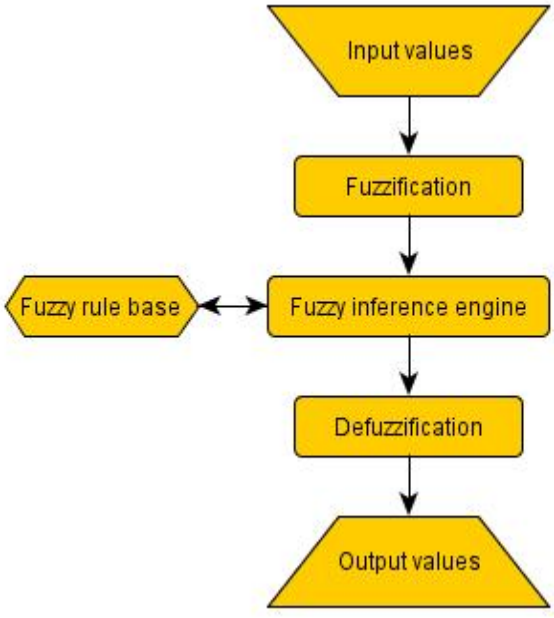

Fig. 5. Basic elements of the fuzzy logic system

Evacuation model control system

The fuzzy logic controlled evacuation model (Fig. 6) uses wind speed and wind direction detectors, gas and heat detectors, automatic and manual alarm systems, and the positions of the terminal workers from different locations of the terminal area with the goal to collect all necessary information for input variables used by the fuzzy logic controller. The controlling is closely related to the previously accumulated experience from QRA, and is copied during the setting of the fuzzy logic controller.

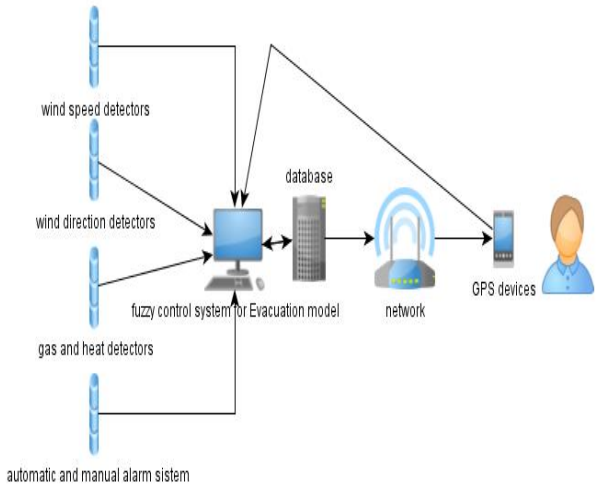

Fig. 6. General structure of the fuzzy control system for an evacuation model

Input and output membership functions

There are four membership functions for the evacuation model for each of the input and output fuzzy variable. The table below (Table 2) shows the **Input fuzzy variables** – the speed of the wind within the area of the terminal (wind speed) as well as the time elapsed after the detection of the accident (time after disaster) as well as **Output fuzzy variable** – the remaining time to reach a point of unacceptable risk in cell X of the terminal (safe time). For purposes of facilitated use of the system fuzzy variables, the relevant abbreviated forms for the variables shall be used hereinafter.

The graphic display of the membership functions of the language variables is shown in Figure 7. The *y*-axis shows the grade of membership for each fuzzy variable. The *x*-axis shows the input fuzzy variables (wind speed, time after disaster) and the output fuzzy variable (safe time). The set up and identification of these membership functions have been determined according to the QRA and a fulfilled database.

Table 2

Fuzzy variables and Fuzzy sets
(Scenario 1: LNG pool diameter 400 m, wind speed 2 m/s)

Linguistic variables	Fuzzy set	Description range
Wind speed (m/s)	very slow (vs)	0 – 1.3
	slow (s)	0.3 – 3.4
	fast (f)	2.8 – 6.2
	very fast (vf)	5.3 – 9>
Time after disaster (s)	very short (vs)	0 – 55
	short (s)	35 – 105
	medium (m)	80 – 175
	long (l)	140 – 250>
Safe time (s)	very short (vs)	0 – 95
	short (s)	55 – 135
	medium (m)	105 – 205
	long (l)	265 – 280>

Fuzzy rule base and defuzzification

The rules of the FUZZY LOGIC controller are based on 'IF-THEN' conditionality. In this case **wind speed** and **time after disaster** are the factors that affect the consequence expressed as **safe time**. We have two variables with Fuzzy Input with four membership functions. According to this the total number of rules applied to the output fuzzy variable safe time is sixteen. The number of rules can also be lesser in some cases, where it is believed that some rules are not necessary or will not change anything in certain situations.

For each cell a separate matrix for fuzzy rules is being created in reference to each scenario which is part of the evacuation model. This is done with the objective that for each individual located in X cell, the fuzzy control system shall use the adequate matrix for the X cell which is intended for the scenario of the accident. As an example, Table 3 shows the matrix for fuzzy rules for evacuation Scenario l in an event when the individual is located in cell number 4.

FUZZY LOGIC controller is using the max-min composition (Mamandi). In the process of defuzzification, the centre of gravity of the received fuzzy set shows the output numerical value. As an example from the following chart (Fig.7) we can see the max-min composition of the 16 rules in the case where the input variables are: **wind speed** 2m/s, **time after disaster** 160 seconds. These values have a grade of membership of 1. The output numerical value for **safe time** after the defuzzification for this case is 55 seconds.

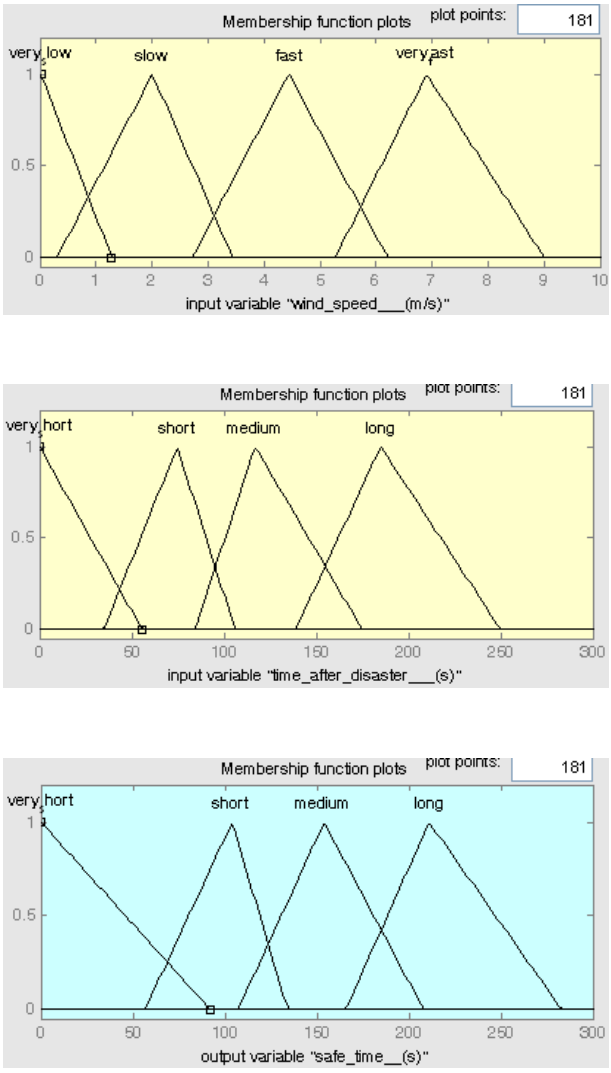

Fig. 7. Graphical presentation of the membership functions to the fuzzy logic controller

Table 3

Matrix for fuzzy rule base for evacuation model

		Safe time			
		Time after disaster			
		vs	s	m	l
wind speed	vs	l	m	m	vs
	s	m	m	s	vs
	f	s	s	vs	vs
	vf	vs	vs	vs	vs

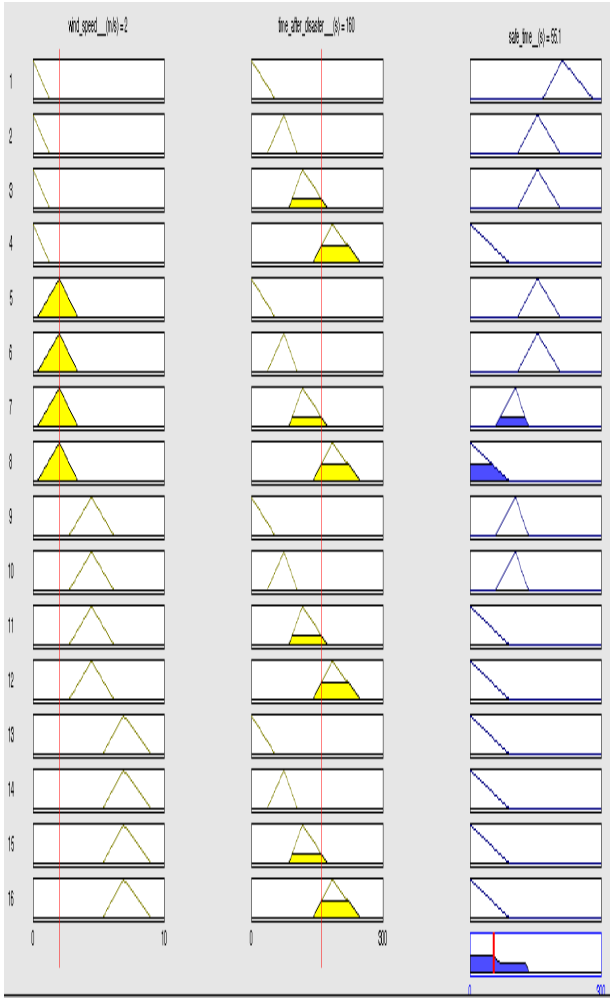

Fig.7: Graphical presentation of the outcome of fuzzy logic controller

Evacuation route

In order for the evacuation model to successfully manage the obtained input and output data, it is necessary to produce a software solution which as a final product provides information to the GPS device of the individual in graphic and sound form via presentation of the evacuation route leading to an area which will not be affected by the influences of the accident. The designed program receives information from the fuzzy logic controller for each cell separately, when the cell will be affected by the accident, and in compliance with this, the program designs potential routes for each individual leading him or her to the final safe destination. The shortest route is the first option that appears on the GPS device of the individual for which the route was created. Under the selected Scenario 1, the individual is located in cell 4. QRA for the starting input data shows that cells 3 and 4 will be influenced by the accident approximately 200 seconds after the accident alert, cells 5 and 6 in approximately 320 seconds, cells 7 and 8 in approximately 380 seconds and cells 9 and 10 in approximately 480 seconds. The evacuation route, starting from cell 4, has an option to lead the individual to one of the three main exits of the terminal located in cells 7, 9 and 10 but also provides additional guidance. The created possible routes primarily indicate the shortest and safest route. Within the whole process of decision-making, an important factor is also the speed of movement of the individual which depends on whether the individual uses a vehicle or is on foot. In situations when time does not allow the individual to be evacuated outside the terminal, the program guides the individual to the nearest terminal safe-haven or shelter.

3. CONCLUSION

LNG leakage accidents are potentially very hazardous. Rapid reaction and evacuation of people is of primary significance. The new ideas for the creation of evacuation models may contribute to the creation of a good evacuation model with a high rate of success in the execution of any evacuation. Through the presented evacuation model, we have portrayed the management of an evacuation model using fuzzy logic for a specific scenario. The potential error during the selection of an evacuation route has been brought down to a minimum in comparison with the selection of an evacuation route by an individual who does not have all the information regarding the external influences on the accident. The advantage of the evacuation model managed via fuzzy logic on the basis of the created database through the carried out QRA is that it eliminates the possibility of an error during the selection of an evacuation route when such is created by an individual with less knowledge of influential temporal factors. Additionally, the program creates a separate safety evacuation route in real time for each individual located inside the terminal on the basis of his/her location after the accident alert. The estimated decrease in risk of course influences the location of new LNG terminals, which must be in compliance with certain safety rules. In any case, this is only a starting point in the development of an evacuation model managed through fuzzy logic. We should also review the possibility for expansion of the use of the model for the needs of the general population, located outside the LNG terminal.

NOMENCLATURE

CFD	Computational Fluid Dynamics
D	Pool diameter (m)
FDS	Fire Dynamics Simulator
Fig	Figure
GPS	Global Positioning System
HAZID	Hazard Identification
HAZOP	Hazard and Operability analysis
LNG	Liquid Natural Gas
LOPA	Layer of Protection Analysis
m	metre
mm	millimetre
m^2	square metre
m/s	metre per second
N	North (cardinal direction)
NE	Northeast (cardinal direction)
NW	Northwest (cardinal direction)
QRA	Quantitative Risk Assessment
s	second
X	number of cell
x , y	Cartesian coordinates
3D	three-dimensional space
°C	degree Celsius

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Original scientific paper

THE INFLUENCE OF THE TECHNOLOGICALLY ADVANCED EVACUATION MODELS ON THE RISK ANALYSES DURING ACCIDENTS IN LNG TERMINAL

Goran Stanković, Stojan Petelin, Marko Perkovič, Peter Vidmar

Faculty for Maritime Studies and Transport, University of Ljubljana,
Pot pomorščakov 4, 6320 Portorož, Republic of Slovenia
gstankovicg@yahoo.com

A b s t r a c t: The evacuation of people located in different safety zones of an LNG terminal is a complex problem considering that the accidents involving LNG are very hazardous and post the biggest threat to the safety of the people located near the LNG leakage. The safety risk criteria define the parameters which one LNG terminal should meet in terms of safety. Those criteria also contain an evacuation as an evasive action with the objective to mitigate the influence of the LNG accident on the people at risk. Till date, not a lot of attention has been paid to technologically advanced evacuations intended for LNG terminals. Creating the technologically advanced evacuation influences directly on the decrease of the probability of fatalities $P_{f,i}$, thus influencing the calculation of the individual risk as well as the societal risk which results in the positioning of the F-N curve in the acceptable part of the ALARP zone. With this paper, we aim to present the difference between the safety analyses in cases when conservative data for $P_{f,i}$ is being used while calculating the risk, and in cases when real data for $P_{f,i}$ is been used.

Key words: evacuation model; LNG terminal; risk analysis; probability of fatality

ВЛИЈАНИЕ НА ТЕХНОЛОШКИ НАПРЕДНИ ЕВАКУАЦИОНИ МОДЕЛИ ВРЗ БЕЗБЕДНОСНИТЕ АНАЛИЗИ НА НЕЗГОДИ ВО ТЕРМИНАЛ ЗА ТЕЧЕН ПРИРОДЕН ГАС

А п с т р а к т: Евакуацијата на луѓето кои се наоѓаат во различни безбедносни зони од терминалот за течен природен гас (ТПГ) е комплексен проблем имајќи предвид дека незгодите со ТПГ се многу опасни и најголема опасност претставуваат за луѓето кои се наоѓаат блиску до истекувањето на ТПГ. Безбедносните критериуми ги дефинираат параметрите кои еден терминал за ТПГ треба да ги исполни од безбедносен аспект. Ваквите критериуми содржат и евакуација како евазивна акција со цел ублажување на влијанието од незгодата со ТПГ врз луѓето под ризик. Сè до денес недоволно внимание беше посветено на технолошки напредни евакуации наменети за терминалите за ТПГ. Креирањето на технолошки напредна евакуација директно влијае врз намалување на веројатноста за смртни случаи, резултирајќи со позиционирање на кривата Ф-Н во прифатниот дел од зоната ALARP. Со овој труд сакаме да ја прикажеме разликата помеѓу безбедносните анализи во ситуација кога имаме конзервативен пристап кон определување на веројатноста за смртност при пресметувањето на ризикот, и во случај кога се користи реално определување на веројатноста од смртни случаи.

Клучни зборови: евакуационен модел; терминал за ТПГ; безбедносни анализи; веројатност од смртни случаи

1. INTRODUCTION

With the ever increasing need of energy in the world, the use of LNG is also increasing. The potential LNG accident with a terminal is potentially very hazardous event. The on time evacuation of people is such situations, despite the complexity of such operation, is of crucial importance and significance. Due to this, the safety analyses include the evacuation as a factor for mitigation of the consequences from the accident. Vanem [1] have made analyses of accidents with LNG tankers where the risk models include evacuation and success levels of the evacuation. Tanabe and Miyake [2] have focused their research on the influences on the risk reduction concept on the basis of design

criteria for emergency systems for LNG plants. The need for development of structural measures for disaster risk reduction, which also includes the evacuation, indicates that special attention should be paid to this type of evasive actions which was not the case so far in terms of the LNG terminals. The multi-year progress of the hazard warning systems is described by Sorensen [3] indicating the lack of researches of evacuations to safe harbors as protective action. The creation of safety evacuation route which is active at the moment of the accident and the fast dissemination to the people for evacuation is essential for eliminating the consequences. In addition, the EU through Horizon 2020 is supporting an extensive number of research projects among which the Mobility for growth which includes the subject matter of Towards the energy efficient and emission free vessel, in which the LNG plays a major role. It is noticeable that the use of LNG is increasing, which results in the need of developing safety policies during the use of the LNG.

Through the following considerations, we want to present and give significance to the advanced evacuation models, during their incorporation into the safety analyses.

2. EVACUATION

The conservative approach during the application of the risk analyses in case of an accident involving LNG leakage and dispersion of the gas, provides a certain assumption that the consequences on the people nearby the accident may be different, i.e. smaller that previously presumed. This is not just due to the uncertainties in modelling incident outcomes or modelling limitations that may lead to conservative assumptions and results, but also due to certain factors such as topography, physical obstruction, but especially die to the evasive actions taken by people.

Some of the possible evasive actions are evacuation, escape, sheltering, heroic medical treatment. Evacuation is a way of increasing the distance between the population and a hazard, and is the counter measure to toxic chemical releases. The term evacuation also describes the extraction of persons from a specific area because of a real or anticipated threat or hazard.

In the last decade the warning process and response, organizational response, behaviour in evacuations, evacuation planning and management has been more in focus than had been the case in the past. The stress has been on the quality of information, the timing of message delivery and the compliance with warnings.

While analyzing the evasive actions, when an LNG accident is in question, a conclusion was reached that the evacuations managed by advanced technology at the same time influence the escape as an evasive action. Due to this, the terms evacuation and escape in this case may be merged and titled as escape with technologically advanced evacuation.

Due to the issue with the inability to select, i.e. identify an escape direction to safe harbor, the probability of escape, during a sudden release of LNG from a LNG vessel, is very low. Prugh, (1985) [4] shows the effectiveness of the evacuation obtained as a function of the warning time, area to be evacuated, and the density of population. This chart may be used to identify the efficiency of the evacuation for various large scale releases, including LNG releases, where sheltering at the location is less desirable. Escape with technologically advanced evacuation was developed during our previous research. The same uses QRA (quantitative risk analysis) to create a database and to obtain experiences for the specific LNG terminal and its environment, with the objective to set the logic used by the managing computer device which uses fuzzy logic in the process of determination (in real time) of the fastest and safest evacuation route for an individual. This model of advanced evacuation which falls under the previously indicated escape with technologically advanced evacuation, plays a certain part in the successfulness of the evacuation, expressed through the decrease of the percentage of individuals which have not been evacuated, i.e. increase of the percentage of successful escapes. This directly reflects on $P_{f,i}$ (Probability of fatality) resulting in its decrease.

3. PROBABILITY OF FATALITY

With the objective to simplify the process of calculation of the individual and social risk, the value referring to the Probability of fatality, is set at 0 or 1. In reality, the Probability of fatality, being graphically presented, is in a form of a curve. For comparison, it is shown in the Figure 1.

If we are to exclude the conservative approach of determination of the Probability of fatality, the same varies depending on the remoteness of the accident and its influence, with a value ranging between 0 and 1.

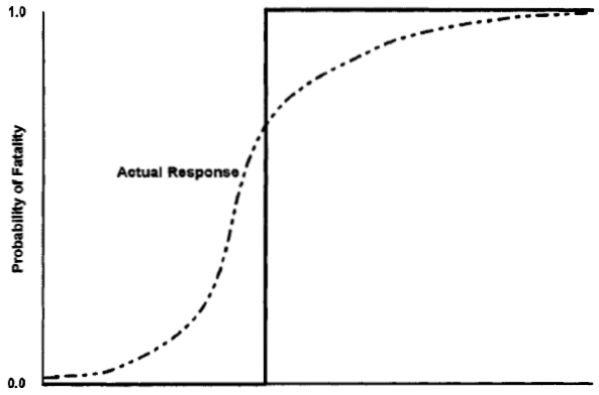

Fig. 1. Probability of fatality

Probability of fatality in a situation where we have technologically advanced evacuation model, is in direct correlation with the difference between the time needed for the individual to reach the safety zone and the time needed for the impact of the accident to reach the final foreseen limit or point. The greater the difference is, the greater the probability for the individual to reach the safety zone, without being impacted by the accident. Adequately, the value of the Probability of fatality is decreasing.

Figure 2 shows the location of the accident with the LNG leakage, the standardized location of work of the employees in the terminal as well as a safe area in which the impact of the accident is brought to a zero.

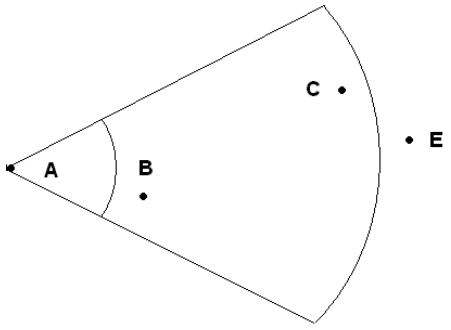

Fig. 2. Accident, employees and safe area location

Point A represents the location of the accident. Probability of fatality in the zone of Point A has a value of 1. Points B and C represent accurately determined locations of the employees in the LNG terminal, where the value for the Probability of fatality for these two points would ranges between 0 and 1 (under a conservative approach of determination of the Probability of fatality, the zone in which are located points B and C would have a value of 1). Point E represents the target or the objective to be reached and the same is located in an area where the impact of the accident equals 0. The individuals located in Point B are at a distance of 550 meters from the accident, while from Point E the individuals are at a distance of 1200 meters. The individuals located in Point C are at a distance of 1300 meters from the accident, i.e. 450 meters from Point E. After the accident occurs and the alarm goes off, the employees in the terminal as well as the automatic safety systems perform all emergency safety measures and the Escape begins with technologically advanced evacuation. The individual located at Point B is to cover 1200 meters in order to reach the safety area in Point E. The usual traveling speed of an individual is 4 meters/s. Having in mind the previous, in approximately 300 seconds the individual will reach Point E. On the other hand, the impact of the accident is nearing the Point B. In compliance with the previously executed QRA, it was concluded that in approximately 200 seconds Point B will be affected. The individual traveling from Point B will reach the safe zone in a total of 300 seconds, while the impact of the accident will reach the final point of around 1600 meters in a total of 500 seconds. Considering this, the calculation shows that the individual has a safe time of around 200 seconds. The greater this safe time is, the smaller the value for Probability of fatality. For comparison, the individuals from Point C will reach Point E in approximately 120 seconds. Compared with the time for the accident impact to reach 1600 meters which is 500 seconds, the calculation indicates 380 seconds of safe time. Also, the Probability of fatality will have smaller value in reference to the individuals located at Point B. This dependency of the Probability of fatality on the safe time as an example is shown in Figure 3.

This manner of determining the Probability of fatality enables identification of a more realistic value of the Probability of fatality, in reference to the conservative principle, having the values 0 or 1.

The use of technologically advanced evacuation model represents a guarantee that these time calculations and differences are applicable in real / actual cases. This will influence the previously stated time difference, i.e. the decrease of the Probability of fatality. Consequently, all of this will also influence the Individual Risk but also the Societal Risk by causing the F-N curve to have a more acceptable positioning in the ALARP zone.

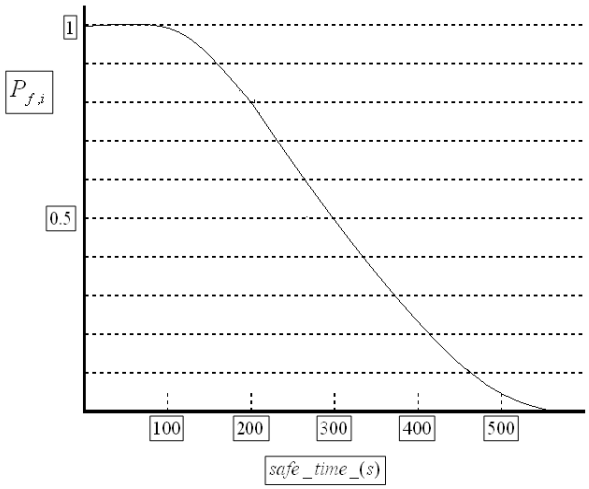

Fig. 3. Dependency of the Probability of fatality on the safe time

All of this enables the technologically advanced evacuation model to be widely accepted as an Evasive action, i.e. to be used with the objective of mitigation of the consequences from the accidents.

4. RISK CALCULATIONS

The objective of conducting the QRA is to identify the potential impact of the LNG leakage accident on the workers in the terminal as well as on the population near the terminal. Risk calculations include calculations of Individual Risk, Societal Risk, and Risk Indices.

Individual risk

Individual risk is the frequency at which an individual may be expected to sustain a given level of harm from exposure to specified hazards. The calculation of IR at a location near a LNG plant, or inside the LNG plant assumes that the contribution of all incident outcome cases are additive. The total IR at each point is equal to the sum of the individual risks at that point, of all incident outcome cases associated with the plant [4] (CPQRA, 4.4 risk calculation).

$$IR_{x,y} = \sum_{i=1}^{n} IR_{x,y,i}$$

where is: $IR_{x,y,i} = f_i \cdot P_{f,i}$; f_i – frequency of incident outcome case i; $P_{f,i}$ – probability of fatality for case i.

Societal risk

Societal risk is the relationship between the frequency and the number of people suffering from a specified level of harm in a given population from the exposure to specified hazards. A common form of Societal risk is an F-N curve (frequency – number), and it is a plot of cumulative frequency versus number of fatalities [4] (CPQRA, 4.4 risk calculation).

$$N_i = \sum_{x,y} P_{x,y} \cdot P_{f,i}$$

where N_i – number of fatalities resulting from incident outcome); $P_{x,y}$ – number of people at the location x, y; $P_{f,i}$ – probability of fatality; $F_N = \sum_i F_i$ for all incidents outcome case i for which $N_i \geq N$; F_n – frequency of all incident outcome cases affecting N or more people; F_i – frequency of incident outcome case i.

5. EXAMPLE RISK CALCULATION PROBLEM

We shall review the model of LNG terminal, in a situation of accident on a moored LNG tanker with leakage of LNG over the water. The LNG leakage accident is considered to be a consequence of intentional breach.

The area around the accident according to SANDIA [5], may be divided in three impact zones: Zone 1 is a distance up to 500m from the accident in which the Probability of fatality for all present individuals is 1. Zone 2 is a distance ranging from 500 to 1600 from the accident. In this case we will review two options for interpretation of the Probability of fatality (Case I – 1 or 0; Case II – values between 0 and 1). Zone 3 is a distance greater than 1600 m from the center of the accident, where the Probability of fatality will be set with a value of 0.

The risk calculation will be applied to a very simple example, with the goal to make the calculations easily comparable, and we will present a calculation of IR and SR under the simplest scenario in which the evacuation is not incorporated into the calculations. We will also present a calculation of the IR and SR with incorporated advanced evacuation with real/actual approach of determination of $P_{f,i}$.

Case I – The evacuation is not included in the calculations

The following simple problem illustrates the risk calculation techniques, using highly simplified frequency and consequence data. It should be emphasized that the risk assessment is been conducted for a LNG terminal at a time of an accident on an LNG carrier during a process of offloading. We shall use highly simplified results for frequency, probability, and consequence and effect estimation.

This example calculation applies the following conditions:

– All hazards originate at a single point;

– The atmospheric stability class and wind speed are always the same. Half of the time wind blows from the south and half of the time from the north;

– The people are located inside the LNG terminal. Their locations will be presented later in the example;

– The probability of fatality from a hazardous incident at a particular location is: for Case I (either 0 or 1).

The incident outcome from the accident of the LNG carrier is release of the LNG onto the water. We are using the event tree logic model to determine additional possible outcomes (Fig. 4). For this example, only two outcomes are assumed to occur. If the formed vapour cloud from the released LNG ignites, there is a Pool fire. If the formed vapour cloud does not ignite, the result is a vapour cloud downwind dispersion from the release point.

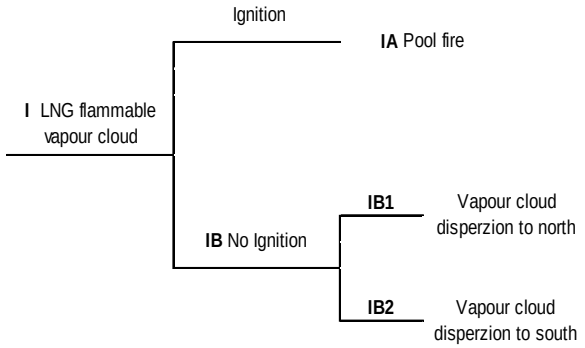

Fig. 4. Event tree for the incident

Very simple impact zone (Fig. 6) estimates for the identified incident outcome cases will be defined:

– Incident outcome case IA (pool fire) – the pool fire is centred at the centre point of the LNG carrier. All persons within 500 metres of the pool fire centre are killed (probability of fatality = 1). All persons beyond this distance are unaffected (probability of fatality = 0).

– Incident outcome cases IB1 and IB2 (LNG vapour cloud dispersion) – all persons in pie shaped (90 degrees) segment of radius of 1600 metres downwind are killed (probability of fatality = 1). All persons outside this area are unaffected (probability of fatality = 0).

Frequency analysis

For this example, it is assumed that the frequency for the incident is $3 \cdot 10^{-5}$ events per year and the ignition probability is around 33%. Previously, we have mentioned that 50% of the time the wind blows towards north, while 50% of the time the wind blows towards the south. The following figure (Figure 5) shows the Frequency estimates for the example incident.

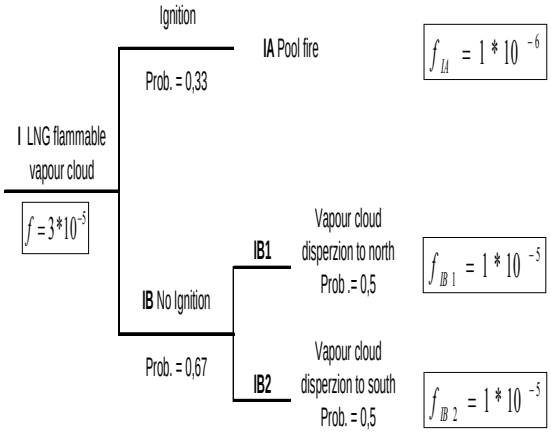

Fig. 5. Frequency estimates for the example incident

Individual risk estimation

The example that we are processing is set in a way to provide simple calculations. Hence, in the zones where $P_{f,I} = 1$, $IR_{x,y,i}$ equals the frequency of that incident outcome case. Outside the impact zone, $IR_{x,y,i}$ is zero. Figure 6 shows the impact zones from the incident. The total individual risk of fatality at each geographical area is determined by adding the IR from all incident outcome case impact zones that impact that area (Table 1).

Table 1

Individual risk of fatality at each geographical area

Area	Incident outcome case	f_i (per year)	P_{fi}	IR_i (per year)
A	IA	$1*10^{-6}$	1	$1*10^{-6}$
	IB1	$1*10^{-5}$	1	$1*10^{-5}$
				$\sum IR_i = 1.1*10^{-5}$
B	IA	$1*10^{-6}$	1	$1*10^{-6}$
	IB2	$1*10^{-5}$	1	$1*10^{-5}$
				$\sum IR_i = 1.1*10^{-5}$
C	IB1	$1*10^{-5}$	1	$1*10^{-5}$
				$\sum IR_i = 1*10^{-5}$
D	IB2	$1*10^{-5}$	1	$1*10^{-5}$
				$\sum IR_i = 1*10^{-5}$
E	IA	$1*10^{-6}$	1	$1*10^{-6}$
				$\sum IR_i = 1*10^{-6}$
F	IA	$1*10^{-6}$	1	$1*10^{-6}$
				$\sum IR_i = 1*10^{-6}$

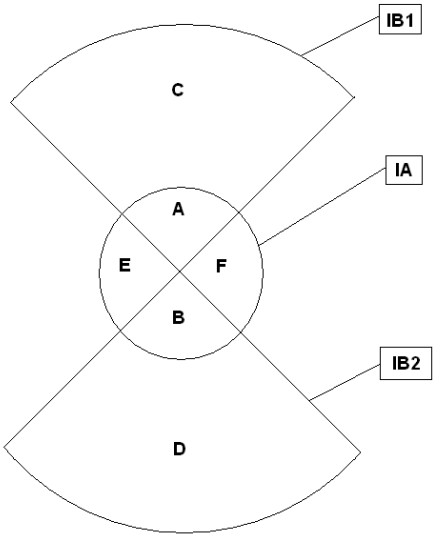

Fig. 6. Impact zones from the incident

Figure 7 shows the number and location of people in the area surrounding the LNG terminal.

The maximum IR is the highest value of IR at any geographical area.

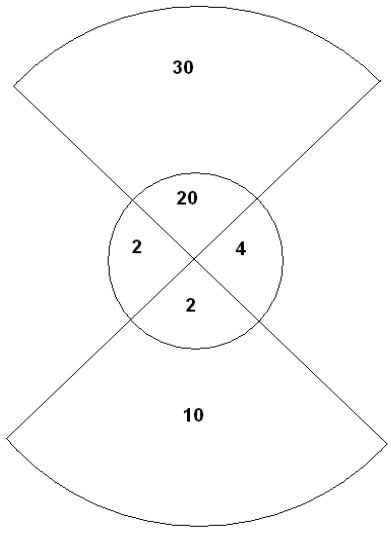

Fig. 7. Number and location of people in the impact zones

Societal risk estimation

The first step while generating the F-H curve is to calculate the number of fatalities as a result of every incident outcome case (Tab. 2).

Table 2

Estimated number of fatalities

Incident outcome case	Frequency per year	Estimaten number of fatalities
IA	$1*10^{-6}$	28
IB1	$1*10^{-5}$	50
IB2	$1*10^{-5}$	12

Table 3 summarizes the cumulative frequency results. Those data are plotted to obtain the societal risk F-N curve (Fig. 8).

Table 3

Cumulative frequency results

Estimaten number of fatalities	Incident outcome case	Total frequency per year
12+	IA, IB1, IB2	$2.1*10^{-5}$
28+	IA, IB1	$1.1*10^{-5}$
50+	IB1	$1*10^{-5}$
>50+	none	0

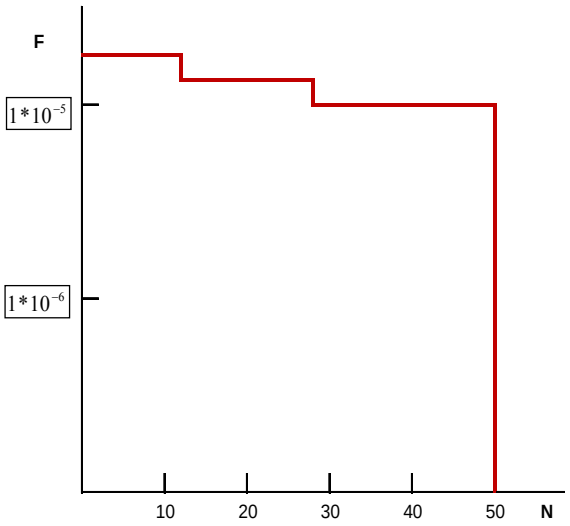

Fig. 8. F-N curve

Case II – Advanced evacuation with actual access of determination of $P_{f,i}$.

In Case II we use the same sample problem as in Case I and apply the same conditions, with a note that for the probability of fatality from a hazardous incident at a particular location we will use data for Case II (between 0 and 1).

We are using the same Event tree logic model to determine additional possible outcomes (Figure 4).

Very simple impact zone (Figure 6) estimates for the identified incident outcome cases will be defined:

- Incident outcome case IA (pool fire) – the pool fire is centred at the centre point of the LNG carrier. All persons within 500 metres of the pool fire centre are killed (probability of fatality = 1). All persons beyond this distance are unaffected (probability of fatality = 0).
- Incident outcome cases IB1 and IB2 (LNG vapour cloud dispersion) – all persons in pies shaped (90 degrees) segment of radius 1600 metres downwind are killed (probability of fatality = between 0 and 1). All persons outside this area are unaffected (probability of fatality = 0).

The frequency analysis remains the same (Fig. 5).

Individual risk estimation

The total individual risk of fatality at each geographical area is determined by adding the IR from all incident outcome case impact zones that impact that area (Table 4). Figure 9 shows the number and location of people in the area surrounding the LNG terminal.

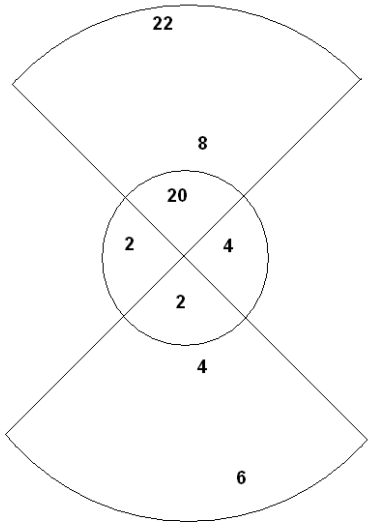

Fig. 9. Number and location of people in the impact zones

Table 4

Individual risk of fatality at each geographical area

Area	Incident outcome case	f_i (per year)	P_{fi}	IR_i (per year)
A	IA IB1	$1*10^{-6}$ $1*10^{-5}$	1 0,57	$1*10^{-6}$ $5.7*10^{-6}$ $\sum IR_i = 6.7*10^{-6}$
B	IA IB2	$1*10^{-6}$ $1*10^{-5}$	1 0,6	$1*10^{-6}$ $6*10^{-6}$ $\sum IR_i = 7*10^{-6}$
C	IB1	$1*10^{-5}$	0,57	$5.7*10^{-6}$ $\sum IR_i = 5.7*10^{-6}$
D	IB2	$1*10^{-5}$	0,6	$6*10^{-6}$ $\sum IR_i = 6*10^{-6}$
E	IA	$1*10^{-6}$	1	$1*10^{-6}$ $\sum IR_i = 1*10^{-6}$
F	IA	$1*10^{-6}$	1	$1*10^{-6}$ $\sum IR_i = 1*10^{-6}$

The maximum IR is the highest value of IR at any geographical area.

The final value of the Probability of fatality for IB1 is obtained as mid value of the Probability of fatality for all locations from IB1 where people are located. The individual Probability of fatality for the people in IB1 and IB2 are determined in Figure 3.

Societal risk estimation

While generating the F-H curve, we calculate the number of fatalities as a result of every incident outcome case (Table 5).

Table 5

Estimated number of fatalities

Incident outcome case	Frequency per year	Estimaten number of fatalities
IA	$1*10^{-6}$	28
IB1	$1*10^{-5}$	37
IB2	$1*10^{-5}$	8

Table 6 summarizes the cumulative frequency results. Those data are plotted to obtain the societal risk F-N curve (Figure 10).

Table 6

Cumulative frequency results

Estimaten number of fatalities	Incident outcome case	Total frequency per year
8+	IA, IB1, IB2	$2.1*10^{-5}$
28+	IA, IB1	$1.1*10^{-5}$
37+	IB1	$1*10^{-5}$
>37+	none	0

The objective of the development and the use of the technologically advanced evacuation model is the dislocation of the people from hazardous areas to safe harbors. The successful dislocation is expressed through presentation of the realistic or actual value of the Probability of fatality (between 0 and 1). The influence on the F-N curve can be seen in Figure 11 (F-N curves for Case I and Case II), where the F-N curve for Case II has more acceptable positioning in the F-N area than in Case I.

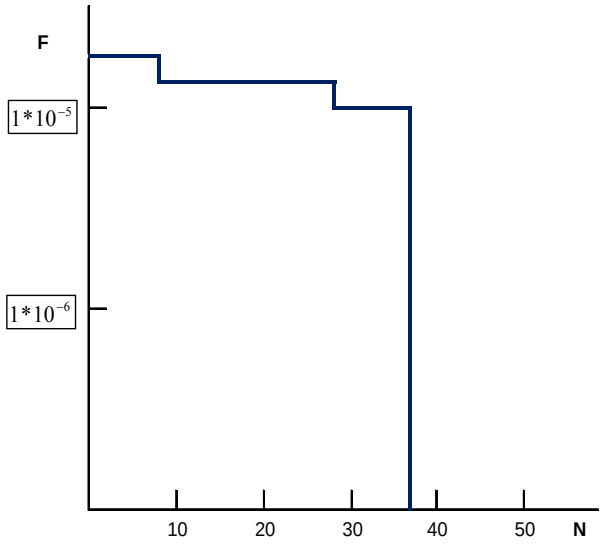

Fig. 10. F-N curve

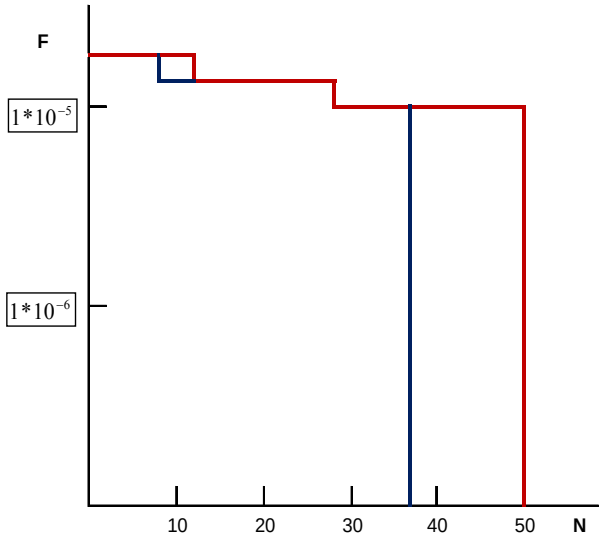

Fig. 11. F-N curves for Case I and Case II

6. CONCLUSION

The development of the technologically advanced evacuation model aimed for people in and outside the LNG terminals, which could be used in situations of LNG leakage accidents, provides the possibility to eliminate the potential errors during the selection of the evacuation routes by an individual or a group of people. In addition, the creation of the evacuation route which is considered the shortest and the safest one, at the same time influences the decrease of the Probability of fatality, which additionally influences the decrease of IR and SR. The difference during the use of the Probability of fatality with a conservative approach

during the determination of the value (0 or 1) and on the other hand the conservative but sufficiently realistic selection of the value for the Probability of fatality (between 0 and 1) is quite evident and we are presenting the same through a simple example. Quality developed and accurately defined technologically advanced evacuation model represents a guarantee for elimination of the underestimation of the value of Probability of fatality, as well as a guarantee that this approach of execution of the risk analyses will provide conservative but at the same time more realistic values.

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Original scientific paper

EMISSION OF CARBON DIOXIDE FROM DIESEL ENGINES WITH EMPHASIS ON EMISSIONS IN REPUBLIC OF MACEDONIA

Dame Dimitrovski, Elena Kitanovska, Mile Dimitrovski, Done Taševski

Faculty of Mechanical Engineering, "Ss. Cyril and Methodius" University in Skopje, P.O.box 464, MK-1001 Skopje, Republic of Macedonia
dame.dimitrovski@mf.edu.mk

A b s t r a c t: This paper presents a research work done on the arising of the air pollutants, which are a result of the combustion of fuel in diesel engines. In addition, there is a data given the increase of the consumption of diesel fuel within several consecutive years. Also there is a graphical representation of the increase of the imported used vehicles in the country, after the reduction of the customs price and excise, and then two scenarios for air pollution from these vehicles are given. In the first scenario, CO_2 emissions are calculated under the current allocation of imported new and used vehicles, while in the second scenario the CO_2 emissions from the imported vehicles are calculated, but this time 2009 was taken as the basis of the ratio of imported new and imported used vehicles, when importation of vehicles was done by the old prices of customs and excise.

Key words: diesel engine; pollution; emission; exhaust; environment; import;.transport

ЗАГАДУВАЊЕ ОД ДИЗЕЛ-МОТОРИ СО ВНАТРЕШНО СОГОРУВАЊЕ СО ОСВРТ НА ЗАГАДУВАЊЕТО ВО РЕПУБЛИКА МАКЕДОНИЈА

А п с т р а к т: Во овој труд е направено истражување на емисиите во околниот воздух кои се резултат на процесот на согорување на горивото кај дизел-моторите. Покрај тоа, дадени се податоци за зголемувањето на потрошувачката на дизел-гориво во неколку последователни години. Исто така е даден графички приказ на зголемувањето на бројот на увезени половни возила во Република Македонија по намалувањето на царината и акцизата, а потоа се направени две сценарија за загадувањето на воздухот од овие возила. Во првото сценарио се пресметани емисиите на CO_2 при моменталната распределба на увезени нови и увезени половни возила, додека пак во второто сценарио се пресметани емисиите на CO_2 од увезените возила, но овојпат како база на односот на увезени нови и увезени половни возила е земена 2009 година, кога увозот на возила се вршеше по старите цени на царина и акциза и трендот на увезени половни возила беше значително помал.

Клучни зборови: дизел-мотор; загадување; емисии; издувни гасови; животна средина; увоз; превоз

1. INTRODUCTION

Diesel vehicles are considered as vehicles that, compared to vehicles with spark-ignition engine, consume less fuel to carry out the cycle, and thus less polluting. However, pollution from diesel engines is greater on local level, and this is a result from the emission of smoke and particulate matter into the atmosphere.

In Republic of Macedonia, about 30% of registered passenger vehicles are with diesel engines, and the trend continues to rise, especially in the years after the price of customs and excise on imported vehicles fell. After the decline of the prices on imported vehicles in 2010, a trend of buying used vehicles imported from Europe or USA in the Republic of Macedonia started with intense. However, despite the dramatic increase in the number of imported used vehicles, an analysis of the environmental impact in the country has not been yet prepared and this situation has left room for very different expert views on this issue.

On one side, by importing used vehicles from European countries or the United States will help many people to replace their old vehicles, which are considered for great polluters of the environment, with newer, thus satisfying the social aspect of residents the Republic of Macedonia. In addition, this will significantly raise the average age of the vehicle fleet in the country and will influence the increase of traffic safety and the improvement of environmental quality. On the other hand, many families can now afford to purchase another vehicle and as a result there will be an increases the number of air pollutants in the country.

2. POLLUTION FROM DIESEL ENGINE VEHICLES

The exhaust gases from diesel engines are a mixture of gases, vapours, liquid aerosols and substances composed of particles. They contain products of combustion, which include nitrogen oxides (NO, NO_2, or NO_x), carbon monoxide (CO), hydrocarbons (HC) and particulate matter (PM) representing solid content in the exhaust gases, which first appears in the form of soot (combustible material, usually carbon) and ash (non-combustible matter, mostly remnants of lubricating oil), water, sulphur oxides and polycyclic aromatic hydrocarbons. The carbon monoxide is a compound of carbon and oxygen produced by the combustion process in the engine [1, 2].

The carbon monoxide is created when the combustion process led to partial oxidation of the carbon particles, i.e. during the process there was not enough oxygen to create carbon dioxide (CO_2). It is a colourless gas, odourless and tasteless, which is poisonous to humans and animals if exposed to greater amounts. The amount of carbon monoxide emitted into the atmosphere from the diesel engines is very small, because they use less fuel to execute the process.

The hydrocarbons (HC) are an organic compound of carbon and hydrogen, that it is backward particles of fuel and lubricating oil, which are not combusted. The level of hydrocarbon particles emitted from the diesel engines is very small, especially if compared with the level of hydrocarbon particles emitted from Otto engines. The amount of hydrocarbons in the exhaust gases of diesel engines is a result of several things: excessive or insufficient mixing of fuel and air, deposits on the walls of the cylinders, fuel leaks, etc.

The nitrogen oxides (NO_x) are created as a result of the reaction between nitrogen and oxygen at high temperature. The formation of nitrogen oxides emissions from diesel engines occurs in poor parts of the flame, during the period of controlled combustion. Because of the short duration of combustion cycle in diesel engines, the complete combustion of nitrogen monoxide (NO) to nitrogen dioxide (NO_2) takes place in the atmosphere. NO_2 can be found in air pollution in major urban centres, and is a highly reactive gas. High concentrations of this pollutant have sharp odour, whereas low concentrations have a similar smell of hydrogen. NO_2 is a major participant in the formation of smog [3].

The particulate matter (PM) is the biggest problem with diesel engines because of the many possible adverse effects on human health. They contain carbon particles-soot. Unlike Otto-engines, where the electric spark ignites the mixture of air and fuel, the ignition in diesel engines starts spontaneously due to high pressure in cylinder. The mixture of air and fuel in a diesel engine is not mixed so thoroughly as in Otto engines, and therefore "pockets" of fuel are created, and when combusted they emit soot [4].

The diesel engines are characterized by a high presence of smoke in the exhaust, black and white. The white smoke usually occurs during cold operation and it is mainly composed of carbon and water vapor. On the other hand, the black smoke occurs at higher engine loads, when bigger amount of fuel is used. It allows the formation of particles of smoke, which essentially are combusted in the cylinder, but a small fraction (about 1%), are discharged into the atmosphere.

The amount and composition of the exhaust gases from the diesel engines depends on:

– The quality of diesel fuel used, such as chemical composition, tendency for evaporation, viscosity, ignition propensity etc. Usually when using fuels with a higher cetane number in diesel engines, there is a greater amount of smoke. This is due to the lower stability of these fuels. Therefore, it is necessary to adjust the characteristics of the fuel to the requirements of the engine;

– The type of engine, e.g. standard, turbo or injector;

– The condition of the engine or the accuracy of the system for fuel supply, condition of the cool-

ing system etc. can significantly affect the flow of combustion and toxicity of the exhaust gases;

– The injection has a great impact on the process of combustion, and thus the effectiveness and efficiency of the engine and exhaust gas composition. Reducing the angle of injection pump for fuel leads to a significant reduction in emissions of NO_x, but also increase emissions of CH, CO and smoke, as well as increased fuel consumption;

– The composition of the mixture influence the composition and quantity of exhaust gases in diesel engines very much. If the mixture is rich than the number of zones with pronounced lack of oxygen is increased, and it results with larger amounts of CO and HC in the exhaust, and larger quantities of smoke;

– Higher air temperature gives higher temperature during the combustion. This affects the combustion temperature of the mixture, and the chemical reactions that contribute to faster oxidation of certain elements.

3. DIESEL ENGINE VEHICLES POLLUTION REDUCTION

In order to significantly reduce the amount of exhaust gases that are emitted into the atmosphere as a result of combustion in diesel engines, there are different technologies used. Because of the specificity of the cycle process development in diesel engines, or combustion in an environment with more air, emissions of CO and HC are small.

On the other hand, the challenge remains to reduce the amount of NO_x, particulate matter and smoke, by making significant efforts in developing new and modern technology.

Some of the technologies used are:

Particulate filters

As the name implies, particulate filters for filtering solid particles from exhaust gases of diesel engines are used. They are made of ceramic elements built in the shape of the hive for honey, mostly from silicon carbide.

Over time these filters are filled from the accumulated particles, ash (a by-emergence from the use of oil for lubricating the engine) and exhaust gases cannot freely pass through the filter. With that comes an increase of the pressure before the filter and if pass certain limits may cause difficulty driving the vehicle or damage to the engine. For these reasons, it is necessary that the filters are cleaned regularly and this is done by combustion or oxidation.

In the case of modern diesel engines, cutting edge technology is used, and the creation of particles is reduced enough to meet the stringent restrictions on emissions of particulate matter.

Catalysts

The catalyst is active component of the catalytic converter. It consists of a substrate (supporting body) coated with precious metal catalyst. The catalytic converter substrates are usually metal or ceramic block, with thousands of tiny channels that pass through it. The channels are coated with material support, which increases their surface, thereby increasing the activity of the catalytic materials. The auxiliary material is coated with a very thin coating of finely dispersed, very small particles of precious metal, such as platinum or combinations with it.The functioning of the catalyst depends on the ratio of air - fuel mixture in the combustion. In conditions of poor mixture, i.e. poor exhaust gas, the catalyst functions as oxidizing catalyst and oxidizes the CO and the HC. However, in terms of working with a rich mixture, the catalyst primarily reduces nitrogen oxides, and then CO and HC (two-stage catalyst). Diesel engines operate with a poor mixture and because of that, the diesel catalyst usually operates as oxidizing catalyst. It reduces emissions of CO and HC for more than 90% [1].

Catalyst for adsorbing the NO_x

NO_x adsorbing catalyst reduces the NO_x from the poor flow of gas through chemical adsorption in the catalyst and subsequent disposal, in conditions of working with stoichiometric or rich mixture. The adsorption process releases CO_2, which then again is re-adsorbed in the process. The adsorbing catalyst has a limited capacity, but it can be regenerated by transferring the flow of exhaust gas resulting from the combustion of a rich mixture into the engine.

System for selective catalytic reduction

The system for selective catalytic reduction works by chemical reduction of NO and NO_2, turning them into N_2 and water H_2O, using as reducing

agent the urea solution, which is added to the exhaust gas. Any source of ammonia can be used, but the most common source is an aqueous solution of urea.

Recycling of exhaust gases – EGR

Recycling of exhaust gases is a technique for reducing the amount of NO_x. The ERG works in a way of returning a given amount of exhaust gases back into the cylinders for combustion. In the case of diesel engines, the recycled exhaust gas replaces a certain amount of oxygen. Because NO_x is produced when a mixture of nitrogen and oxygen is subjected to high temperature, lower temperature in combustion chamber caused by EGR, reduces the amount of NO_x in the exhaust, but at the expense of some reduction of the engine performance.

4. AIR POLLUTION FROM THE TRANSPORT SECTOR IN REPUBLIC OF MACEDONIA

The majority of motor fuels sold in the Republic of Macedonia are used in the transport sector, in light passenger vehicles. In the period from 2002 to 2006 in the country, more than 97% of energy consumption in the transport sector was made by passenger traffic.

The passenger traffic, that comprises passenger vehicles (about 88%), trucks, motorcycles, accounts for 92% of total generation of polluting substances emission, all of which come from the transport sector in the country, and the other mobile sources, that include rail, road and international air traffic, contributes with 8% of total emissions [5].

The problems of air pollution are more pronounced in urban areas. The state of traffic systems in our cities is unique because it largely does not meet fundamental principles, which are closely related to environmental modalities in modern cities. In fact, such traffic systems affect the mobility of traffic connection of separate parts of the city, and with the reduction of the speed of motor vehicles through the city streets the motor consumes more fuel, and there are larger amounts of polluting substances emitted (Fig. 1).

On the Figure 1, given below, the distribution of total emissions of pollutants from the transport sector in the Republic of Macedonia in the period from 2001 to 2009 is shown. In the total annual emissions from all sectors nationwide, for the period 2001 to 2009 year, the largest share of the transport sector emission belongs in NO_x emission (32–87%).

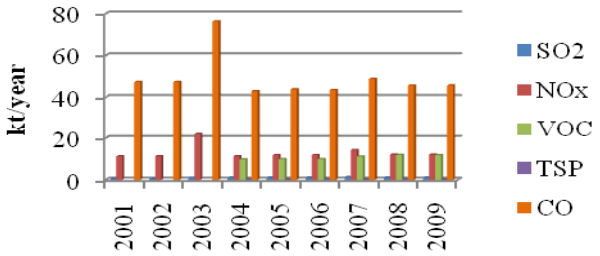

Fig. 1. Distribution of total emissions of pollutants from the.transport sector

5. AIR POLLUTION FROM DIESEL ENGINES IN REPUBLIC OF MACEDONIA

According to the number of vehicles in the country, the number of spark-ignition engines is dominating, although there is a clear trend of increasing number of diesel engine vehicles and the number of vehicles that use a combination of gasoline and LPG. In 2006, about 72% of the vehicles used gasoline, 24% used diesel fuel and about 4% used a combination of gasoline and LPG (Fig. 2).

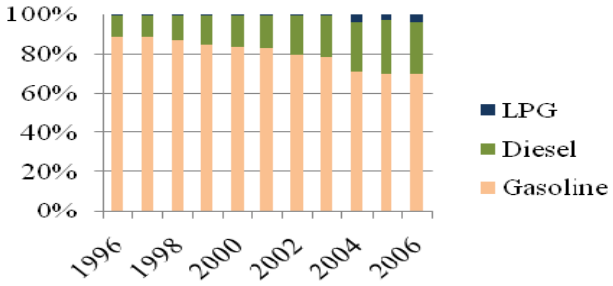

Fig. 2. Distribution of passenger vehicles, according to the fuel type

Over the years, the trend of using diesel vehicles in the Republic of Macedonia is increasing. On the Table 1 the distribution of passenger vehicles, by the fuel type in 2012, is shown.

Table 2 shows the number of registered passenger vehicles that use diesel fuel, depending on the type of vehicle, for the period from 2009 to 2012, and the trend of growth of the usage of diesel vehicles.

Table 1

Distribution of passenger vehicles, according to the fuel type in 2012

	Number of vehicles	%
Gasoline	199329	66,05
Diesel	92700	30,72
Mixture	190	0,065
Gasoline-gas	9501	3,15
Electrical power	41	0,015
Total	**301761**	**100**

Table 2

Number of registered diesel fuel passenger vehicles

	2009	2010	2011	2012
Motorcycles	281	201	633	325
Passenger cars	54 200	71 713	85 248	92 700
Buses	1 973	2 232	2 212	2 327
Freight vehicles	18 693	19 744	19 415	17 804
Work vehicles	436	461	478	446
Towing vehicles	3 454	3 714	3 883	3 561
Tractors	584	516	847	946
Total	**79 621**	**98 581**	**112 716**	**118 109**

Figure 3 below shows the consumption of diesel fuel in passenger vehicles, during the period from 2005 to 2010, in the Republic of Macedonia.

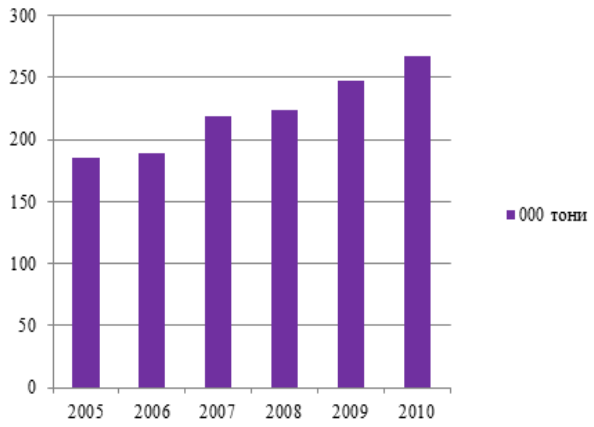

Fig. 3. Consumption of diesel fuel in passenger vehicles during the period from 2005 to 2010

6. EUROPEAN EMISSION STANDARDS

Before a vehicle can be approved for sale in the European Union, it must meet certain emission standards specified in the EU Directives. Currently there is a set of standards (limits) for the following polluting substances:

– nitrogen oxides (NO_x),
– total hydrocarbons (THC),
– hydrocarbons that contain methane (NMHC),
– carbon monoxide (CO) and
– particle matter (PM).

Limiting the quantity of polluting substances in the exhaust gases from the engine are different for a given type of vehicle, including cars, trucks, tractors and similar machinery, excavators. For each type of vehicle, different standard is applied. In addition, there is a difference between the restrictions for engines with compression ignition (diesel) and engines with spark ignition (spark-ignition engines).

Compliance requirements and the actual amounts of polluting substances in the exhaust gases are determined by a standardized test cycle with engine running. The vehicles with bigger emission than the approved cannot be sold in the European Union.

Euro 1 and Euro 2

Euro 1 standard is defined within the Directive 91/441/EES, for passenger cars only, but then the Directive 93/59/EES was adopted, which beside passenger cars also included the light trucks. Euro 2 standard is defined in the Directive 94/12/ES and 96/69/ES. Euro 2 DI standard was valid until 30.09.2009.

Euro 3 and Euro 4

Emission standards Euro 3 and Euro 4 are defined in the Directive 98/69/ES, and then enhancing it with Directive 2002/80/ES. In this Directive, in Euro 3 standard, special restrictions on the amount of nitrogen oxides in the exhaust gases were included, in addition to restrictions on the amount of HC + NO_x.

In order to achieve the requirements of the standards Euro 3 and Euro 4 in Europe commonly used ways were installing the oxidizing catalysts in diesel for reducing CO and HC.

Euro 5 and Euro 6

For diesel engines, there are two sets of constraints that must be implemented: Euro 5a and Euro 5b, while the Otto engines have only one - Euro 5. The implementation of Euro 5 and Euro 5a standards started in September 2009 and Euro 5b entered force in 2011.

The standard Euro 5b, for the first time, includes a limit on the amount of particle number (PN). Euro 5 is improved compared to Euro 4 with more focus on the emission of particulate matter from diesel engines. Euro 5 requires installing the particle matter filters, diesel vehicles, and restricts that the emissions of particulate matter can be at most 5 mg/km.

In September 2014 the implementation of the standard Euro 6 will begin. Research of the European Commission showed that by reducing emissions of nitrogen oxides, as required by Euro 6, the health conditions would improve for more than 60–90% in comparison to the Euro 5 standard. In addition, Euro 6 gives the same limit on the number of particles in the exhaust as diesel and Otto engines.

In order to fulfil the Euro 5 and Euro 6 standards in terms of emissions of particulate matter, all passenger cars with diesel engine must be constructed with filter for solid particles (Tab. 3).

Republic of Macedonia, as a country not yet a member of the European Union, it is not obliged to comply with the European regulations. On the other hand, as a candidate for membership in the European Union, Republic of Macedonia has started intensive alignment and harmonization of national legislation with the legislation of the European Union. This section also included harmonization of laws, by-laws and regulations of the transport sector, and subsequently the introduction of the European emission standards for new and used vehicles.

With the purpose of meeting the limitations of the given amounts of emissions, the Directives do not require the need to use certain specific technology for reducing emissions, but the establishment and adoption of standards takes into account current technology that exists on the market.

Major technologies required to meet each stage of Euro emission limits, like improvement of the combustion air induction, riceing injection pressure and variable geometry turbocharger for air induction tailoring, showed in Table 3.

Table 3

Major technologies required to meet each stage of Euro emission limits [6]

	Technologies
Euro 2	• Rotary fuel pump • IDI combustion • Low pressure: 700–800 bar • ERG low pressure mechanic operation
Euro 3	• DI combustion • Injection pressure: 1300 bar • Cooled ERG • DOC for PM reduction
Euro 4	Euro 3 technology, plus: • A/F management and combustion improvements • Electronic control of fuel injection • Injection pressure: 1600 bar • Engine tuning and mapping • 4 valves per cylinder • Electronically controlled EGR
Euro 5	Euro 4 technology, plus: • Improvement in the combustion air induction • Injection pressure: 1900 bar • Tumble and swirl • Variable geometry turbocharger • DOC+DPF • Variable valve timing • LNT may be required in some engines
Euro 6	Euro 4 technology, plus: • Injection pressure: 2100 bar • Variable geometry turbocharger for air induction tailoring • DOC+DPF+LNT

7. IMPORT OF USED VEHICLES FROM M1 CATEGORY IN REPUBLIC OF MACEDONIA

The adoption of the Law on Amending the Law on Customs Tariff in 2010, the Republic of Macedonia lowered the excise and customs on imported new and used vehicles. Besides the change in the law, a new Rulebook for.single approval of a vehicle was adopted. According to the Rulebook, all imported vehicles must meet the technical requirements defined in it, which vary depending on the category they belong.

The Rulebook for single approval of vehicles provided a limitation of emissions depending on the category of vehicle in relation to his body shape. This paper is for vehicles in category M1, including: limo, moving vehicles, coupe, convertible, armorer vehicles, etc. or according to the Directive 95/48/ES, these are vehicles with length – 12 m, width – 2,5 m, and height – 4 m [6, 7, 8].

In terms of limiting emissions from the exhaust of vehicles belonging to category M1, whether diesel engine or Otto engine, under the Rulebook, during the period from March to September 2010, import of Euro 1 vehicles was allowed. Once that period expired, so in the next six years, until August 2016, the import will be allowed for vehicles with Euro 2 standard and above. The adoption of these amendments, the Republic of Macedonia has started intensive importation of used vehicles and the number of new imported vehicles fell.

Figures 4 and 5 show the change in the total number of imported new and used passenger vehicles in the period from 2009 to 2013, and the cumulative change in the number of imported vehicles, where the dramatic increase in the import of used vehicles I shown, as well as the significant reduce of the imported new vehicles.

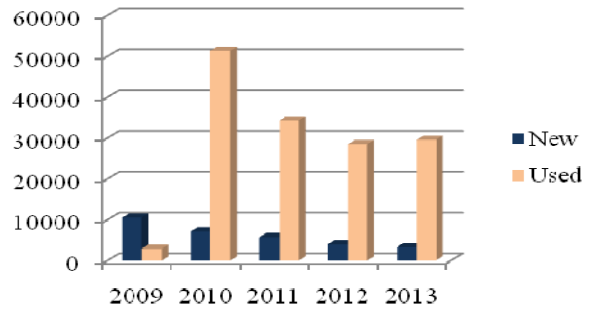

Fig. 4. Number of imported passenger vehicles in the period 2009–2013

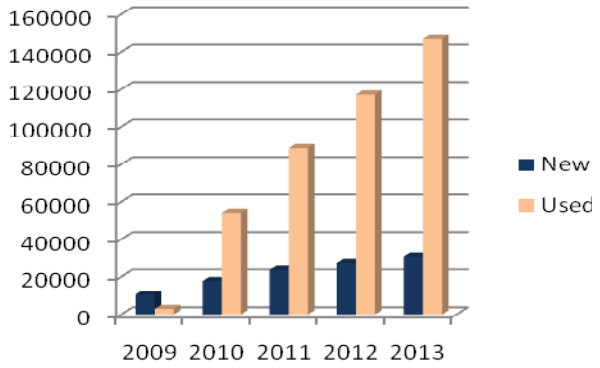

Fig. 5. Cumulative number of imported passenger vehicles in the period 2009–2013

8. SCENARIOS FOR CO_2 EMISSIONS FROM THE IMPORTED DIESEL VEHICLES

In this part of the paper, two scenarios in terms of CO_2 emissions from imported diesel passenger vehicles in the country were considered (Tab. 4):

– In the first scenario the calculation of CO_2 emissions was carried out under the current allocation of imported new and used imported vehicles.

– In the second scenario the CO_2 emissions calculation from imported vehicles was executed again, but this time, the year of 2009 was taken as a base of the ratio of imported new and used imported vehicles, when the importation of vehicles was carried out with the old prices of customs and excise and the trend of imported used vehicle was significantly lower. In 2009 the ratio was about 80% imported new vehicles and 20% imported used vehicles.

In order to perform these calculations, the following assumptions were made:

– According to Table 1, the percentage of registered diesel passenger vehicles was 30% in 2012. For these calculations, the same percentage was taken.

– The CO_2 emissions from new cars are 120 g_{CO_2}/km, and from used cars they are 160 g_{CO_2}/km.

– A car with a diesel engine annually passes an average of 20.000 km.

The calculations were made for the period from 2010 to 2013, when the import of used vehicles is greatest.

Figure 6 shows results from the calculations for both of the Scenarios.

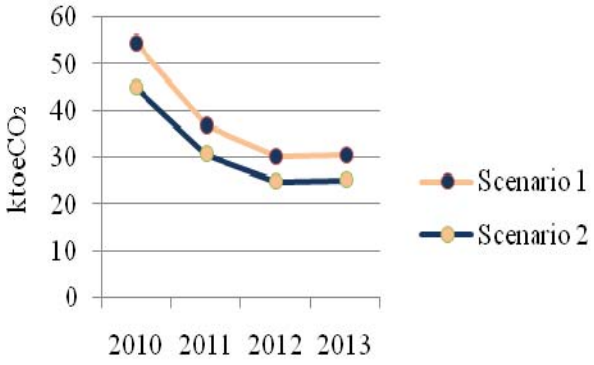

Fig. 6. CO_2 emissions according to the scenarios

It is evident that when the bigger share of the imported vehicles would have been new vehicles, than the air pollution from them would have been significantly lower. As the number of imported used vehicles grows, respectively the amount of CO_2 emissions rises. This is noticeable especially in 2010, when the import od used vehicles was intensive, so it is expected that in this year there will be the biggest difference in the CO_2 emission.

Table 4

CO_2 emissions scenarios for the imported diesel vehicles

	2010		2011		2012		2013	
	Sc.1	Sc. 2	Sc. 1	Sc. 2	Sc. 1	Sc. 2	Sc. 1	Sc. 2
CO_2 emissions (kton)	54.51	44.99	37.09	30.81	30.29	25.01	30.73	25.22

Note:
– Scenario 1: CO_2 emissions calculation under the current allocation of imported new and used imported vehicles.
– Scenario 2: CO_2 emissions calculation, where the year of 2009 was taken as a basis of the ratio of imported new and used imported vehicles, when the ratio was about 80% imported new vehicles and 20% imported used vehicles.
– The percentage of registered diesel passenger vehicles was 30% in 2012. For these calculations, the same percentage was taken.
– The CO_2 emissions from new cars are 120 g CO_2/km, and from used cars, they are 160 g CO_2/km.
– A car with a diesel engine annually passes an average of 20.000 km.

9. CONCLUSION

From the graphs and tables it can be seen that in 2010 there was a dramatic increase in the number of imported used vehicles as a result of measures to lower the prices of customs and excise on imported vehicles. But also, it be noted that analogous to the proliferation of imported used vehicles comes to declining number of new imported vehicles.

With the increase of the number of imported used vehicles it can be assumed that there is an increased air pollution, especially if you assume that if there was a no reduction in customs, then instead of import of used vehicles there would be import of new vehicles, and in that way the pollution would be less. It can be seen in the calculations of both scenarios.

From Figure 2 it may be noted that in the country, every year, the number of vehicles with diesel engines rises, and according to these data it can be assumed that the ratio of vehicles with diesel engines – Otto engines is similar today. Although diesel engines use less fuel than Otto engines, and thus emit les amounts of pollutants in the atmosphere, the increase in the number of vehicles increases the air pollution.

It is worrying that after 2010 the total number of registered passenger vehicles in the country has significantly increased, and this is due to the increased number of imported used vehicles and the fact that right now almost every family can afford more vehicles.

After four years of implementation of these measures, it is necessary to prepare a detailed study of the impact on the environment of imported used vehicles over this period, but also, now, when there is real data about the interest about the purchase of these vehicles, it is necessary to make a possibles scenarios for the upcoming years.

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Original scientific paper

TRAINING NEEDS OF WOMEN ENTREPRENEURS IN THE WESTERN BALKANS, TURKEY AND MOLDOVA

Bojan R. Jovanovski[1], Igor Nikoloski[2], Radmil Polenakovik[1], Trajče Velkovski[1], Emilija Nikoloska[3]

[1]*"Ss. Cyril and Methodius" University in Skopje, Faculty of Mechanical Engineering, Karpoš II bb, P.O. box 464, 1001 Skopje, Republic of Macedonia*
[2]*National Centre for Development of Innovation and Entrepreneurial Learning, Dame Gruev 1/2 -17, 1000 Skopje, Republic of Macedonia*
[3]*Ministry of Education and Science of Republic of Macedonia, Centre for Adult Education, Vasil Gjorgov 35, 1000 Skopje, Republic of Macedonia*
bojan.r.jovanovski@mf.edu.mk

A b s t r a c t: This paper is addressing the gap between the current skills, the required and the future expected skills of both the business leaders and the other employees in companies owned and managed by women entrepreneurs. The research covers the Western Balkans, Turkey and Moldova, providing overview of the reasons for organizing training, taking into consideration the problematic areas that need to be addressed, the potential benefits as well as the most important topics for development of the personal. The results also present the demographic specifics of the women entrepreneurial enterprises around the region and their human capital development activities and future intentions. The research methodology has been verified by a regional working group, whose members have been responsible for the implementation of the survey.

Key words: women entrepreneurship; training needs analysis; skills mismatch

ПОТРЕБА ОД ОБУКА НА ЖЕНИТЕ ПРЕТПРИЕМАЧИ ВО ЗЕМЈИТЕ ОД ЗАПАДЕН БАЛКАН, ТУРЦИЈА И МОЛДАВИЈА

А п с т р а к т: Овој труд се фокусира на јазот помеѓу поседуваните, сегашните и идните вештини и компетенции на менаџментот и на другите вработени во компаниите поседувани и управувани од жени претприемачи. Истражувањето ги опфаќа земјите од Западен Балкан, Турција и Молдавија и дава осврт на причините за организирање обука, со посебен акцент на проблематичните области, можните придобивки, како и најважните сфери за развој на вработените. Резултатите ги покажуваат и демографските специфики на претпријатијата на жените претприемачи во регионот во кој е спроведено истражувањето, нивните сегашни, но и планираните активности за развој на човечкиот капитал. Истражувачката методологија е верификувана од страна на регионална работна група чии членови беа одговорни за спроведување на анкетата.

Клучни зборови: женско претприемништво; анализа на потребата од обука; јаз во вештини и компетенции

1. INTRODUCTION

The development of the SME (Small and Medium size Enterprises) sector is the backbone of every economy. In the EU, this sector represents more than 99% of all enterprises in the economy [1]. The European Commission recognises that entrepreneurship and small businesses are a key source of jobs, business dynamism and innovation and promoting entrepreneurship is a clear objective for achieving the Lisbon goals (to make the EU "the most competitive and dynamic knowledge-based economy in the world capable of sustainable economic growth). Europe is not fully exploiting its entrepreneurial potential, and lags behind the United States in both business start-ups and self-

employment. Women entrepreneurship is also important to the EU for both gender equality and economic growth. "In terms of policy recommendations, stakeholders underline the importance of better data on which to base policies, as well as the reinforcement of support structures for female entrepreneurs such as the provision of information and training, business networks, business support services, and facilitating access to both human and financial capital for women" [2]. The Global Entrepreneurship Monitor has shown that an average entrepreneur is double more likely to be male than female [3], which indicates that it is necessary to address the women entrepreneurs as a specific target group in order to provide custom made support for starting and growing of their businesses.

According to the study undertaken by the European Commission in 2008 on women innovators and entrepreneurs [4], there were identified: three types of women's obstacles to innovative entrepreneurship:

1. Contextual obstacles: educational choices, traditional views and stereotypes about women, science and innovation;

2. Economic obstacles: innovation sector requiring substantial investment and women being seen less credible financially than men;

3. Soft obstacles: lack of access to technical scientific and general business networks, lack of business training, role models and entrepreneurship skills.

Based on this, the group soft obstacles play an important role in lacking the women to foster and expand businesses. Due to this, according to the EU Small Business Act for Europe 10, the skills mismatch is going to stay very high in the EU agenda, which was confirmed with the EU 2020 Strategy documents. By renewed emphasis by current European Commission policies for a more entrepreneurial Europe and for women entrepreneurship as a priority pillar within the SBA (Small Business Act), ensuring policy alignment, monitoring systems and support frameworks for women's entrepreneurship requires a concerted commitment by all pre-accession countries to bring forward and ensure improvements in women's employment and participation in the economy.

Training is a fundamental element in fostering the competitiveness of women entrepreneurs and an instrument that support companies growth and development. The system analyses of the training needs are essential in order to design the training in such manner that can be tailored specifically to existing enterprises' needs. This eliminates provision of training which is overabundant and increases provision of training which is lacking - which results in greater system efficiency.

2. RESEARCH METHODOLOGY

In order to conduct effective research, the implementing team has designed the following research methodology:

Phase I: *Establishment of a regional working group*

Working group composed on 9 participants from relevant institutions from the researched countries was established. The working group's main objectives were verification of the methodology, adaptation of the questionnaire and conducting the survey.

Phase II: *Analysis of TNA good practice methodologies*

The implementation team have analyzed the good practice methodologies for national and regional training needs analysis methodologies. The scope of the analysis has also included women entrepreneurship specific aspects, as well as regional aspects and good practices.

Phase III: *Development of the methodology and the survey questionnaire*

Based on the analysis, the implementation team have developed the TNA methodology and questionnaire. The finalization of these documents was verified with the working group including country specific aspects, as well as business sector interest into the methodology.

Phase IV: *Data collection process*

The survey was conducted through online data collection system, translated into all of the countries' languages. Each working group member in cooperation with women business support organizations in their respective country promoted and supervised the implementation of the survey process. After the finalization of this process, 1856 successfully filled in questionnaires from 9 countries were uploaded on the on-line data base.

Phase V: *Preparation of country report*

Each working group member has prepared country specific report. The reports presented the background information for women entrepreneur-

ship in the respective country, including new developments and national policies, the results of the project, as well as overview of the lessons learned and the recommendations for future similar actions

Phase VI: *Preparation of a regional report with recommendations for future actions*

The implementation team have analysed the data, reviewing relevant literature and prepared the final report and recommendations for future actions.

3. DATA COLLECTION AND SAMPLE INFORMATION

According to the methodology, the survey was conducted online through a virtual Microsoft database. In total 1856 acceptable questionnaires were filled in the data base, with the following distribution per country: Albania 201 questionnaires, Bosnia and Herzegovina 136, Croatia 282, Kosovo 202, Macedonia 209, Moldova 206, Montenegro 182, Serbia 203, Turkey 235 questionnaires. In total, the objective, collecting at least 1800 questionnaires was accomplished. Montenegro and Bosnia and Herzegovina are the only participants that did not manage to achieve country's minimum of 200.

Considering the sectorial involvement in the survey, it can be concluded that 16% of all participants are coming from the Wholesale and retail trade, repair of motor vehicles and motorcycles, followed by Professional, scientific, technical and support service activities (15%) and Manufacturing sector (11%). Companies from Mining and quarrying, Electricity, gas, steam and air conditioning supply and Water supply; sewerage, waste management and remediation activities were least present, with representation of only 2% for the three sectors together. There was not such sector that did not have representation in the survey.

The largest group of companies in the Albanian survey comes from the medium sized manufacturing companies and in Bosnia and Herzegovina from small sized manufacturing companies. Turkey is the only country where the biggest group is in among the medium sized companies, in the particular case also in manufacturing. Croatia, Kosovo, Macedonia, Moldova, Montenegro and Serbia have the largest group among micro-enterprises mainly operating in the sector of wholesale and trade.

Most of the enquired owners possess university undergraduate diploma, apart from Kosovo and Albania. In the case of Albania more than 60% of the entrepreneurs have either Master or PhD diploma. Apart this, in Kosovo, more than 50% of the entrepreneurs have finished high school. Kosovo also have highest portion of women entrepreneurs with only primary education, followed by Montenegro and Turkey (Fig. 1).

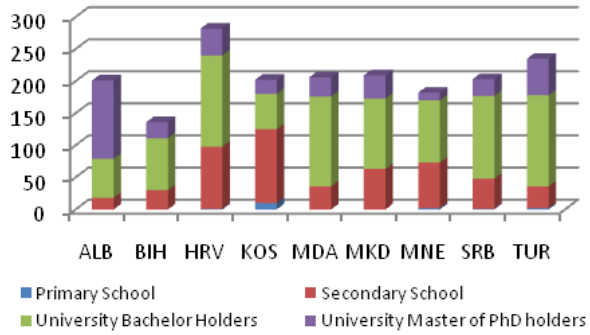

Fig. 1. Educational background of the enterprises' owners

If this data are compared to the data received by the age of the owners, it can be concluded that in Kosovo, many young women do not continue with higher education, rather they start a business. The same pattern applies to Albania as well, since most of the entrepreneurs in Albania are aging 40 and above that confirms that after finalizing the higher education they decided to open their own business.

By saying this, it can be only suggested for consideration that in the case of Albania, the idea for initiating a business come from information and data gathered and processed during the studies at the Universities focusing more in innovation, research, fact driven approach, compared to Kosovo where most of the business are either trade oriented or required basic and technical skills to run a business in the area of manufacturing.

Almost two out of three companies have stated that they currently have good business performance (mark 4 on the scale out of 5), and only one in every 140 companies have stated that they are in a process of phasing out and closing their activities.

Considering this data, it can be confirmed that SMEs managed by women are performing very well in this time of global economic crisis and those should be taken and promoted as best examples. On the other hand, it can be also considered that companies that were in the phases "Barely

surviving" or "Phasing out" and the reason have refused to participate in this project. Due to this assumption only more active and more successful companies did take part in the survey, which might not represent the real situation on the ground (Fig. 2).

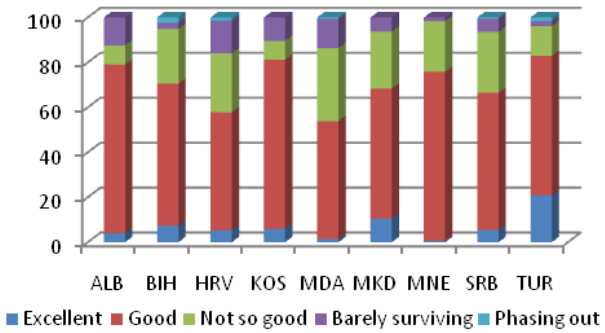

Fig. 2. Current business performance per country (%)

Most of the respondents have stated that their current business performance is evaluated as good. Entrepreneurs from Macedonia, Montenegro, Kosovo and Albania, do not have companies that are in "Phasing out" stage. On the other hand, Moldova and Montenegro have reported only small portion of companies (equal to none) that are in "excellent stage" of performance.

Many articles and reports [5] in the past have stated that women are still considered as unexplored working potential, due to their intensive household responsibilities. Still, this research states the opposite. In the women managed enterprises work more female employees (52%), compared to (48%) men employees. This might indicate that women prefer employing women.

On the other hand the most of the employees working for women entrepreneurs following under the age group of 30–39 years, followed by the age group of 16–29 years. Only few employees come from the age group above 60 years.

The overview of the regional survey shows that almost half of the employees enrolled in the survey have finished secondary education, 1/3 has obtained undergraduate diploma, 1/14 master or PhD, and 1/7 possess only primary school diploma. Only 1% of employees has no schooling or have unfinished primary education

The educational structure of the enrolled employees per country is corresponding with the overall regional overview, with moderate deviations, such as the higher number of masters and PhD holders in Albania, much higher than average low number of primary school employees in Turkey, and much lower in Moldova and Montenegro. These deviations have occurred, partially as a result of the educational structure in the respective country, but also from the country's sample type, size and sector of operation. For example, most of the employees with finished only primary education, are working in companies with 100 – 250 employees, and in case of Turkey they have been represented with 9%, which is 6 times more than in the Moldova's and in Montenegro's sample there are not even included. As larger the total number of employees in the company is, the greater the percentage of lower educated employees may be expected.

The entrepreneurs have stressed that an increase of competition, the need of improvement of quality, the attitudes and working behaviour of the employees and the access to finance and capital are one of the most important areas with the strongest impact on the enterprise functioning. On the other hand, they have stated that the change of top management, adaptation to environmental factors, the increase of industrial accidents and the technological changes do not influence the business performance at all compared to other factors/areas (Fig. 3).

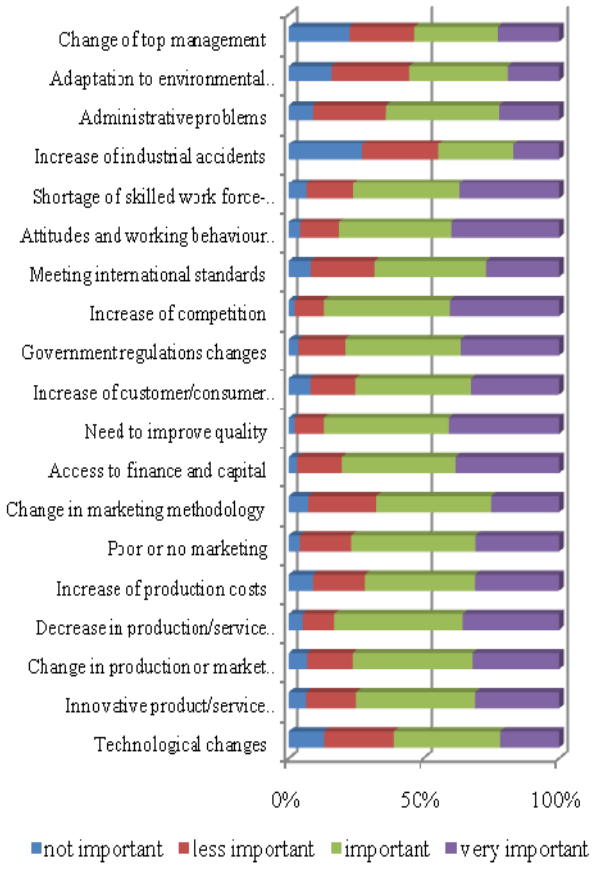

Fig. 3. Business impact areas

4. KEY FINDINGS

a) *Structural setting*

The way how trainings organized differs from one country to another. Companies from Albania, Moldova and Montenegro, prefer training to be organized internally by company own experts. On the other hand, Macedonian companies prefer outsourced services, while Turkey, Serbia and Kosovo use the combination of both. Completely outsourced trainings have been organized less frequently, especially in Serbia (Fig. 4).

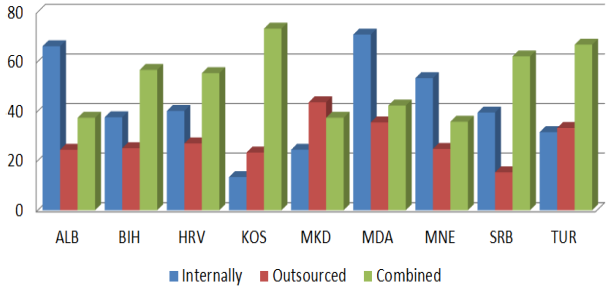

Fig. 4. Organziation of training (%)

The business culture and the company structure are the main factors that influence the company's perception towards HRD. Still, when it comes to the responsibilities for HRD and the training in the company, the results across the enterprises in these countries follow similar pattern. In other words, the most responsible subject in more than half of companies (57%) is the director. The largest deviation is noticed in Kosovo, where around half of the companies do not have a person/department that is responsible for this issue. In Turkey, this responsibility is equally distributed between director, owner and the HR manager/Department (Fig. 5).

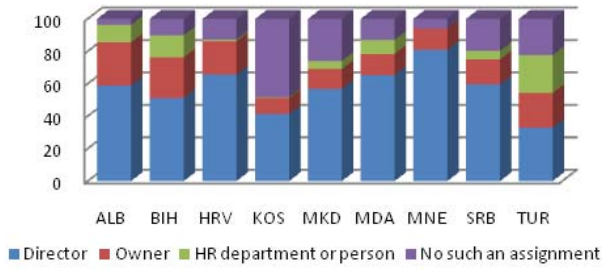

Fig. 5. Responsibility for the HRD and training (%)

The responsibility for HRD and training can be also considered by the size of the company. So, even based on this, the director is still the main responsible subject in more than half of the companies with 1 – 99 employees. However, for companies that employee more than 100 employees, there is special HR Department or person who has the responsibility to plan the human resource development with the company. This confirms the fact that in the smaller companies there is no need of employing a HR person or creating a separate department. Also, in small portion of around 20%, no matter of the size of the company the owner is responsible for HRD and training related issues. Interesting finding shown by the survey is that in 15–20% of the companies, main responsible for HRD is the owner, without influence by the company's size (Fig. 6).

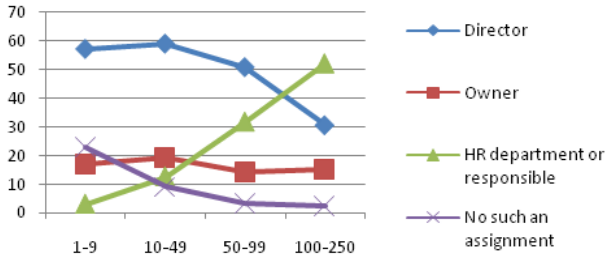

Fig. 6. Responsibility for HRD and training by the size of the companies (%)

Training can lead to business performance improvement at any aspect. Still, the most important reasons why training is organized is because it can contribute to increasing the quality of products and services, preparation of new employees to the tasks they need to perform and it can improve the image of the enterprise. This shows that the trainings and education for increasing of the skills and knowledge of owners and employees usually have wider range of goals and expected outcomes for the company (Fig. 7).

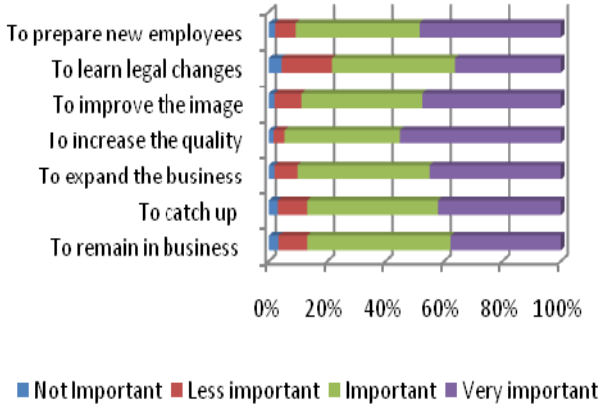

Fig. 7. Reasons for organizing training

Overall on a regional level, 85% of respondent enterprises have stated that they do not allocate training budget. This shows that the awareness for HRD is still not institutionalized and implemented in the strategic focuses of the women managed SMEs. When it comes to company budget allocation for training per country the situation differs from one country to another. Only 2% of companies from Kosovo have stated that they have reserved annual budget for training. Other countries that also have small portion of companies (less than 10%) that have budget allocation for training are Montenegro and Moldova. On the other hand, more than 30% of the companies from Albania (32%) and Turkey (31%) that participated in this survey have reported that have annual reserved budget for training. Additional factor influencing the allocation of budget is the size of the company meaning larger the company - higher allocation of annual budget for HRD (Fig. 8)

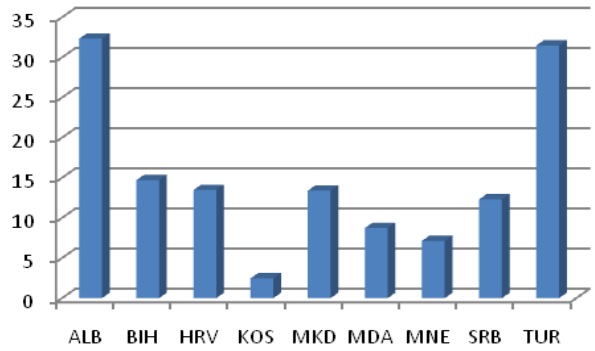

Fig. 8. Companies' reserving budget for training per country (%)

More than half of the companies (58%) have stated that their investments in HRD are the same in the last three years, 28% of them have confirmed that their budget has increased, while 14% have budget cuts when it comes to training. The analysis covers the period after the first years of the world financial crisis, comparing the years of stabilization and return of growth of the global economy (Fig. 9).

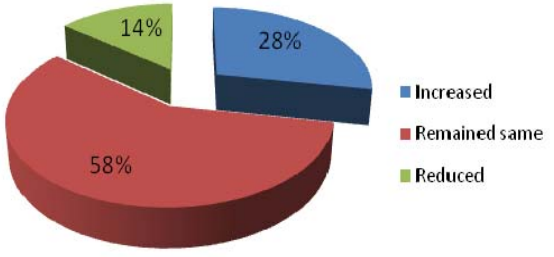

Fig. 9. Trend of investments for HRD in the last three years

The main source of funding for the HRD is provided by the enterprises themselves (69%), followed by employees own resources (18%). The international organizations and their projects participate with 9%, along with the public funds with only 4% as alternative sources of funding for HRD and training. Although this information shows that more than 2/3 of the companies, as a main source of funding for trainings are relying on their own budget, still it is not enough to confirm that they consider this as an investment that can bring in future more efficiency and effectiveness to the company's performance, having in mind that only 15% are planning this investment ahead. The lack of not having the proper structure and organization for tracking the HRD in the company makes the situation for managers/owners very difficult since they do not have the right information for the volume and focus of the trainings that their employees attend by their own.

When it comes to the region specifics, the situation in Kosovo is quite different from the other countries, where more than 60% of the companies have stated that their employees are the main sources of financing for HRD activities. Part of this deviation has occurred due to the different structure of the Kosovo's sample, where 95% of the respondents are in the group of 1–9 employees, compared with the average of 70%. On the other hand, 20% of the companies in Macedonia, Albania and Kosovo rely on international organisations and projects for training (Fig. 10).

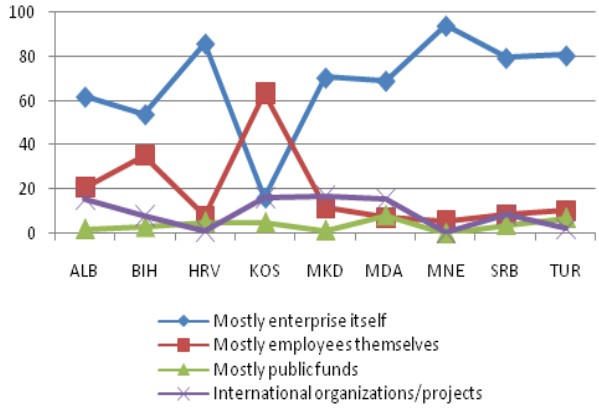

Fig. 10. Sources of funding for HRD per country (%)

As active partner in the business development process, and additionally as promoters of different training initiatives, chambers of commerce are selected as the most commonly used training provider. Apart from those, other groups of preferred

training providers are the private companies as well as the individual experts. The least important providers are defined the secondary schools and the vocational education and training centres together with universities (Fig. 11).

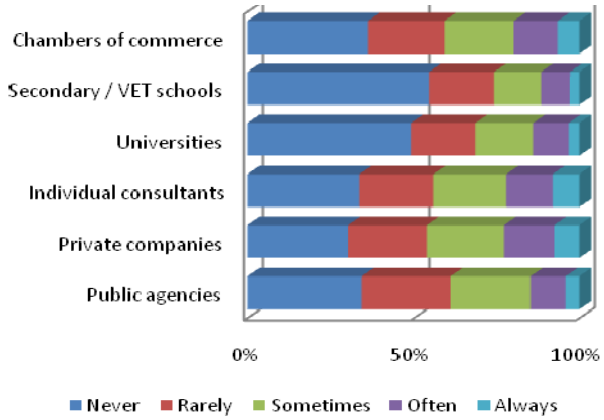

Fig. 11. Preferred training providers

The research has shown that expected benefits of the training and the trainer's quality / eligibility as main factors for selection of HRD programme. As secondary factors, the price and the information on training have been selected. The least important factors are identifies the provision of certificates, location of the training and the proper timing (Fig. 12).

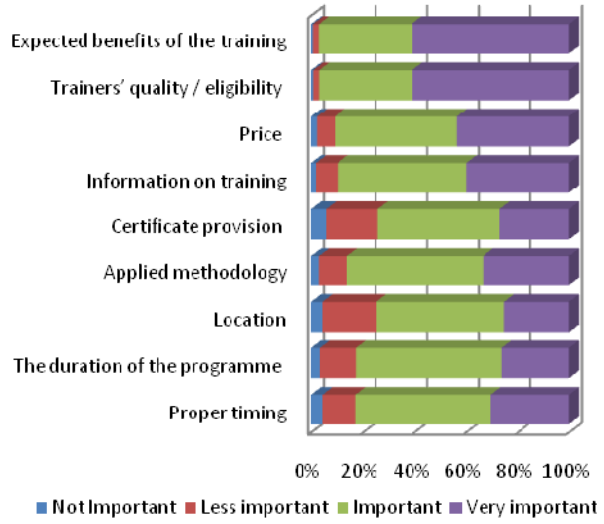

Fig. 12. Selection factors for HRD

b) *Training topics*

The research has shown that the most important training topics for the owners and managers are - product and service development, management issues, marketing and sales, strategic planning and organization, as well as market trends. Although, all of the proposed topics have been rated with relatively high importance, also less important topics have been presented: internationalization, innovation and intellectual property rights, and efficient use of energy.

On the other hand, other employees have stated that product and service development, marketing and sales and market trends, are most important topics for HRD. Less important topics were defined the following - internationalization, financial management and accounting, management, as well as trainings regarding incentives and new legislation.

The comparison between the two categories of employees (owners and managers as one group and other employees as other) shows that apart from the trainings for human resource, for all other trainings there is a difference in the importance of the topics for the managerial and non-managerial staff. The largest deviation of more the 0.1 index points is considered at the following trainings – management and information and computer technology (Fig. 13)

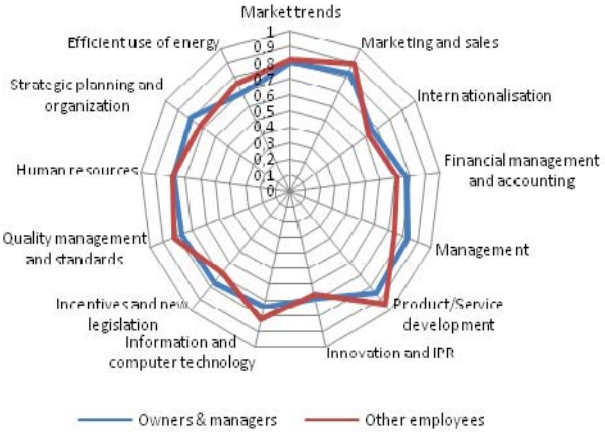

Fig. 13. Importance of training topics for owners, managers and other employees

. Owners and managers have rated all proposed topics as very important, especially customer oriented services (93%), leadership and motivation (90%) and presentation skills (87%), except mathematical-numerical skills, which was rated with relatively low importance, identified by 40% of the respondents as not or less important.

On the other hand, the employees have selected the customer oriented services as the most

important for business development. But according the EU legislation and directives and mathematical-numerical skills, finance, accounting and controlling, as well as organization and management, have been rated as the least important topics.

The surveyed companies' representatives, owners and managers have presented much higher importance of all training topics for their own development and the development of other managers, compared to the overall significant for the HRD of the other employees. Regarding the difference of the relative importance inside the two groups, the respondents have put customers oriented services, presentation skills, conflict and problem solving, as well as communication on mother tongue, as the most important for the other employees. For the owners and managers, the customer oriented services, leading and motivating and presentation skills have been identified as most important topics.

Mathematical and numerical skills have been identified as not important by both groups (Fig. 14).

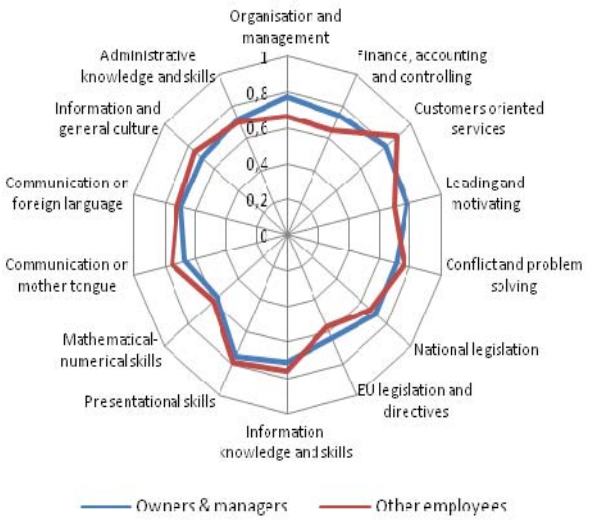

Fig. 14. Required training for development of owners, managers and other employees

5. CONCLUSIONS

Based on the results collected, the following conclusions can be drawn:

- There is a need to further raise the awareness regarding the benefits of using the training services.
- There is a lack of information regarding training offers.
- Women entrepreneurs are optimistic and have positive attitudes about their business performance.
- There is a need to draft a specific tailor-made policy measures with reference to women entrepreneurs.
- Availability of financial services should be more widely disseminated.
- Companies are relatively satisfied by the training providers and quality of their services.
- Training services are still expensive and they are considered as a cost to the companies, not as an investment in HRD.
- Public training support is still very limited.
- Companies are the main source of funding for HRD.
- Media are the main source of information when it comes to training offers as well as availability of financial services.
- Companies plan to increase their dedicated budget for training in the future.
- Companies prefer to organize the training after work hours or during weekends.

The main focus in the future should be given to two parallel sets of activities.

The first one, should be oriented on continues raising the awareness about the long-term benefits that training can produce for a company. The initial activity in this respect is to adapt the mind-set of the entrepreneurs that cost for the training is an investment and asset for the company and its employees, rather than liability the uses financial and human resources without earning corporate gains. Once this is approach is accepted, then it is easy to start think and to plan the other activities related to continuous increasing the knowledge and skills of the management and employees in order to get for efficient and more competitive company.

The second set of activities is related to assuring the quality of the training and receiving the appropriate skills and competence development in order to bridge the gap that currently exists in the company. In this respect, the most important issue is to know to identify what you need (in terms of training), selecting the right provider to deliver the training as well as to be able to benchmark the company performance before and after the training is being delivered.

6. RECOMMENDATIONS

1. Adoption of concrete measures and activities with concrete focus of specific target groups.

Adoption of general SME policy measures are important for each economy since they provide the roadmap towards which each country should be heading. Still, in all countries, apart from those general measures additional sets of activities should be developed having in mind the specifics of the different target groups, such as women or young entrepreneurs, unemployed starting up a business due to the need of existence, ex-convicts trying to adjust into the system, etc.

2. Identification of best practices from this research and their promotion in order to raise the awareness and to stimulate the implementtation of effective SME training programmes. Implementation.

Public promotion and dissemination of the results should be conducted in each country in order to raise the awareness among women and other entrepreneurs in human capital. Those examples should be used as a model lesson learnt of how the business performance can be improved, SME development as well as how the company success can be achieved while investing in the human resources.

3. Establishment of national WE SME Forum in each country that could focus on several key issues in the area of training and HRD in the SME sector.

This Forum could be tripartite including the women entrepreneurs on one side, training providers and business support organisations on the other side, and Government institutions, SME Agencies and policy makers on the remaining side. This will ease the process of bridging the gap between the training supply and demand.

4. Regular organisation of the 'train the trainers' sessions (by the supply side) that will secure the quality of the trainers, will help them better to understand the SME and will be able to design the specific tailor made products depending on the market/region/sector characteristics.

A number of counsellors coming from the private sector that have more many years of experience in a given area, nowadays are actively engaged by the SMEs. The counsellors' experience can be used in order to ease the implementation of the concept 'train the trainers' based on the challenges and opportunities they had to face over their working experience. By delivering training to a number of trainers, that later on will transfer this knowledge to the SME sector, can create more competitive and cheaper training offers and can assure the quality of the training.

5. To ease the access to information regarding public and Government programmes that provides specific WE SME support. To create a centrally managed national WESME web based portal where all this information can be easily approached.

To create a national web portal for WE SME where all relevant information will be published and regularly will be updated on a daily basis. This portal will contain information regarding the legislation, finances, intellectual property rights, provision of grants, as well as all active WE SME policy support measures and activities.

6. Implementation of different types of needs assessment to SME managed by women entrepreneurs, apart from TNA.

Based on the current TNA, to develop a methodology and questionnaire and to implement a survey where are needs of the SME managed by women entrepreneurs will be considered, such as finance or legal related needs assessment, where specific needs regarding these subjects will be considered. Based on the data gathered, concrete policy measures could be developed.

7. Implementation of specific TNA by NACE sectors, or targeting specific group of enterprises (i.e. export oriented).

Based on this analysis and other experiences, it can be stated that the training needs are not the same among different sectors or group of companies. Using the sector specific TNA will ensure more qualitative results, meaning in-depth analysis could be prepared for concrete group of companies with similar economic activities, and based on this also specific policy measures can be adopted. This

will increase the quality of the training offers, since more specific and concrete needs will be identified for smaller and homogenous group of companies.

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Original scientific paper

VEHICLE ROUTING AND SCHEDULING – THE TRAVELING SALESMAN PROBLEM

Dejan Krstev[1], Radmil Polenakovik[2], Mirjana Golomeova[3]

[1] *"Ss. Cyril and Methodius" University in Skopje, Faculty of Mechanical Engineering, IE&M, Logistics, Karpoš II bb, P.O. box 464, 1001 Skopje, Republic of Macedonia*
[2] *"Ss. Cyril and Methodius" University in Skopje, Faculty of Mechanical Engineering, Karpoš II. bb, P.O. box 464, 1001 Skopje, Republic of Macedonia*
[3] *Faculty of Natural and Technical Sciences, Krste Misirkov bb., 2000 Štip, Republic of Macedonia*
krstev.deni@gmail.com

A b s t r a c t: The classification of routing and scheduling problems depends on certain characteristics of the service delivery system, such as size of the delivery fleet, where the fleet is housed, capacities of the vehicles, and routing and scheduling objectives. In the simplest case, we begin with a set of nodes to be visited by a single vehicle. The nodes may be visited in any order, there are no precedence relationships, the travel costs between two nodes are the same regardless of the direction traveled, and there are no delivery-time restrictions. In addition, vehicle capacity is not considered. The output for the single-vehicle problem is a route or a tour where each node is visited only once and the route begins and ends at the depot node. The tour is formed with the goal of minimizing the total tour cost. This simplest case is referred to as a **traveling salesman problem (TSP)**. An extension of the traveling salesman problem, referred to as the **multiple traveling salesman problems (MTSP)**, occurs when a fleet of vehicles must be routed from a single depot. The goal is to generate a set of routes, one for each vehicle in the fleet. The characteristics of this problem are that a node may be assigned to only one vehicle, but a vehicle will have more than one node assigned to it. There are no restrictions on the size of the load or number of passengers a vehicle may carry. The solution to this problem will give the order in which each vehicle is to visit its assigned nodes. As in the single-vehicle case, the objective is to develop the set of minimum-cost routes, where "cost" may be represented by a dollar amount, distance, or travel time. If we now restrict the capacity of the multiple vehicles and couple with it the possibility of having varying demands at each node, the problem is classified as a **vehicle routing problem (VRP)**. In this paper will be presenteds the TSP procedure for delivery and routing of new product L-carnitine from Koding – Skopje which life development is in the introduction or development phase.

Key words: TSP; L-carnitine; routing; service

РУТИРАЊЕ И РАСПОРЕД НА ВОЗИЛО – ПРОБЛЕМ НА ТРГОВСКИ ПАТНИК

А п с т р а к т: Класификацијата на проблемите на рутирање и распоред со сигурност зависи од карактеристиките од сервисот на системот за испорака, брзината на испораката, местото каде се испорачува, носивоста на возилото и целите на рутирањето и распоредувањето. Во наједноставниот случај се започнува со мрежа на јазли во кои се движи поединечно возило. Јазлите можат да се посетуваат по кој било ред, не постои никаков приоритет во релацијата, врз патните трошоци помеѓу два јазла не влијае правецот на возење и не постојат рестрикции за времето на испорака. Исто така, носивоста на возилото не се зема предвид. Турата се формира со цел да се минимизира вкупниот трошок на турата. Наједноставниот случај е означен како проблем на трговски патник (TSP). Проширувањето на проблемот на трговски патник е означено како повеќекратен проблем на трговски патник (MTSP), кој се појавува кога брзината на возилото мора да биде рутирана од поединечен склад. Целта е да се генерира мрежа на рути, една за секое возило. Не постојат ограничувања во големината на товарот или бројот на патници за возилото да може да носи. Решението на овој проблем ќе го даде редот по кој секое возило ги посетува предвидените јазли. Во случајот на поединечно возило, целта е да се развие мрежа од рути со минимални трошоци, каде што трошокот може да се претстави во износ на долари, растојание или време на патување. Ако се намали носивоста на мултиплицираните возила и се обединат со можноста за варијација на потребите за секој јазол, проблемот се класифицира како проблем

на рутирање на возило (VRP). Во овој труд ќе се прикаже процедурата TSP за испорака и рутирање на нов производ – L-карнитин од Кодинг – Скопје, кој се наоѓа во фазата на развој на животниот циклус.

Клучни зборови: TSP; L-карнитин; рутирање; сервис

1. INTRODUCTION

The scheduling of customer service and the routing of service vehicles are at the heart of many service operations. For some services, such as school buses, public health nursing, and many installation or repair businesses, service delivery is critical to the performance of the service. For other services, such as mass transit, taxis, trucking firms, and the Postal Service, timely delivery *is* the service. In either case, the routing and scheduling of service vehicles has a major impact on the *quality* of the service provided, C. Haksever et al. [1].

This introduction has showed some routing and scheduling terminology, classifies different types of routing and scheduling problems, and presents various solution methodologies. Although every effort has been made to present the topic of vehicle routing and scheduling as simply and as straightforward as possible, it should be noted that this is a technical subject and one of the more mathematical topics in this text.

A private, nonprofit meal delivery program for the elderly called Meals-for-ME has been operating in the state of Maine since the mid-1970s. The program offers home delivery of hot meals, Monday through Friday, to "home-bound" individuals who are over 60 years of age. For those individuals who are eligible (and able), the program also supports a "congregate" program that provides daily transportation to group-meal sites. On a typical day within a single county, hundreds of individuals receive this service. In addition, individuals may be referred for short-term service because of a temporary illness or recuperation. Thus, on any given day, the demand for the service can be highly unpredictable. Scheduling of volunteer delivery personnel and vehicles as well as construction of routes is done on a weekly to monthly basis by regional site managers. It is the task of these individuals to coordinate the preparation of meals and to determine the sequence in which customers are to be visited. In addition, site managers must arrange for rides to the "group meals" for participating individuals.

Although these tasks may seem straightforward, there are many practical problems in routing and scheduling meal delivery. First, the delivery vehicles (and pickup vehicles) are driven by volunteers, many of whom are students who are not available during some high-demand periods. Thus, the variability in available personnel requires that delivery routes be changed frequently. Second, because the program delivers hot meals, a typical route must be less than 90 minutes. Generally, 20 to 25 meals are delivered on a route, depending on the proximity of customers. Third, all meals must be delivered within a limited time period, between 11:30 A.M. and 1:00 P.M. daily. Similar difficulties exist for personnel who pick up individuals served by the congregate program. Given the existence of these very real problems, the solution no longer seems as simple. It is obvious that solution approaches and techniques are needed that allow the decision maker to consider a multitude of variables and adapt to changes quickly and efficiently, O. C. Ferrell et al. [3] и Paul Fifield [4],

2. OBJECTIVES AND CHARACTERISTICS OF ROUTING AND SCHEDULING PROBLEMS

The objective of most routing and scheduling problems is to minimize the total cost of providing the service. This includes vehicle capital costs, mileage, and personnel costs. But other objectives also may come into play, particularly in the public sector. For example, in school bus routing and scheduling, a typical objective is to minimize the total number of student-minutes on the bus. This criterion is highly correlated with safety and with parents' approval of the school system. For dial-a-ride services for the handicapped or elderly, an important objective is to minimize the inconvenience for all customers. For emergency services, such as ambulance, police, and fire, minimizing response time to an incident is of primary importance. Thus, in the case of both public and private services, an appropriate objective function should consider more than the dollar cost of delivering a service. The "subjective" costs associated with failing to provide adequate service to the customer must be considered as well.

Routing and scheduling problems are often presented as graphical **networks**. The use of networks to describe these problems has the advantage of allowing the decision maker to visualize the problem under consideration. The anyone figure

consists of some circles called **nodes**. For example, four of the five nodes (nodes 2 through 5) represent pickup and/or delivery points, and a fifth (node 1) represents a **depot node**, from which the vehicle's trip originates and ends. The depot node is the "home base" for the vehicle or provider.Connecting these nodes are line segments referred to as **arcs**. Arcs describe the time, cost, or distance required to travel from one node to another. Given an average speed of travel or a distribution of travel times, distance can be easily converted to time. However, this conversion ignores physical barriers, such as mountains, lack of access, or traffic congestion. If minimizing time is the primary goal in a routing and scheduling problem, then historical data on travel times are preferable to calculations based on distances. Arcs may be directed or undirected.

Undirected arcs are represented by simple line segments.

Directed arcs are indicated by arrows. These arrows represent the direction of travel in the case of routing problems (e.g., one-way streets) or precedence relationships in the case of scheduling problems (where one pickup or delivery task must precede another).

The route for the vehicle also called a **tour.**

The tour is a solution to a simple routing problem where the objective is to find the route that minimizes cost or any other criterion that may be appropriate (such as distance or travel time). The minimum-cost solution, however, is subject to the tour being **feasible**.

Feasibility depends on the type of problem, but, in general, implies that:

1) a tour must include all nodes,

2) a node must be visited only once,

3) a tour must begin and end at a depot.

The output of all routing and scheduling systems is essentially the same. That is, for each vehicle or provider, a route and/or a schedule is provided. Generally, the **route** specifies the sequence in which the nodes (or arcs) are to be visited, and a **schedule** identifies when each node is to be visited.

3. THE TRAVELING SALESMAN PROBLEM

The traveling salesman problem (TSP) is one of the most studied problems in management science. Optimal approaches to solving traveling salesman problems are based on mathematical programming. But in reality, most TSP problems are not solved optimally. When the problem is so large that an optimal solution is impossible to obtain, or when approximate solutions are good enough, heuristics are applied. Two commonly used heuristics for the traveling salesman problem are the **nearest neighbor procedure** and the **Clark and Wright savings heuristic**.

a) *The Nearest neighbor procedure*

The nearest neighbor procedure (NNP) builds a tour based only on the cost or distance of traveling from the last-visited node to the closest node in the network. As such, the heuristic is simple, but it has the disadvantage of being rather shortsighted, as we shall see in an example. The heuristic does, however, generate an "approximately" optimal solution from a distance matrix. The procedure is outlined as follows:

1. Start with a node at the beginning of the tour (the depot node).

2. Find the node closest to the last node added to the tour.

3. Go back to step 2 until all nodes have been added.

4. Connect the first and the last nodes to form a complete tour.

b) *Clark and Wright savings heuristic*

The Clark and Wright savings heuristic (C&W) is one of the most well-known techniques for solving traveling salesman problems. The heuristic begins by selecting a node as the depot node and labeling it node 1. We then assume, for the moment, that there are $n \rightarrow 1$ vehicles available, where n is the number of nodes. In other words, if we have six nodes in the network, then there are five vehicles available. Each vehicle travels from the depot directly to a node and returns to the depot. But this is not a feasible solution because the objective of a traveling salesman problem is to find a tour in which all nodes are visited by *one* vehicle, rather than by two vehicles. To reduce the number of vehicles needed, we now need to combine the $n \rightarrow 1$ tours originally specified.

The key to the C&W heuristic is the computation of savings. *Savings* is a measure of how much the trip length or cost can be reduced by "hooking up" a pair of nodes and creating the tour $1 \rightarrow 2 \rightarrow 3 \rightarrow 1$, which can then be assigned to a single vehicle.For a network with n nodes, we compute the savings for every possible pair of

nodes, rank the savings gains from largest to smallest, and construct a tour by linking pairs of nodes until a complete route is obtained.

A statement of the C&W savings heuristic is as follows:

1. Select any node as the depot node (node 1).

2. Compute the savings, *Sij* for linking nodes *i* and *j*:

$$S_{ij} = c_{1i}\, c_{1j} + c_{ij} \quad \text{for} \quad I \quad \text{and} \quad j \text{ nodes } 2, 3, K, n \tag{1}$$

where: c_{ij} – the cost of traveling from node *i* to node *j*.

3. Rank the savings from largest to smallest.

4. Starting at the top of the list, form larger **subtours**by linking appropriate nodes *i* and *j*.

Stop when a complete tour is formed.

4. MULTIPLE TRAVELING SALESMAN PROBLEM AND VEHICLE ROUTING PROBLEM

The MTSP is a generalization of the traveling salesman problem where there are multiple vehicles and a single depot. In this problem, instead of determining a route for a single vehicle, we wish to construct tours for all *M* vehicles. The characteristics of the tours are that they begin and end at the depot node. Solution procedures begin by "copying" the depot node *M* times. The problem is thus reduced to *M* single-vehicle TSPs, and it can be solved using either the nearest neighbor or Clark and Wright heuristics. The classic VRP (Vehicle Routing Problem) expands the multiple traveling salesman problems to include different service requirements at each node and different capacities for vehicles in the fleet. The objective of these problems is to minimize total cost or ***TSP Solver and Generator.*** By means of the applicative software it's possible to optimize TSP procedure, providing the appropriate procedure for optimal transport decision of the energetic new product L-carnitine in the region of the eastern part of the Republic of Macedonia. The Figure 1 has showed distances between cities where product are distributed from the Koding-Skopje enterprise, distance across all routes. Examples of services that show the characteristics of vehicle routing problems include different Services deliveries, public transportation "pickups" for the handicapped, and the newspaper delivery problem etc.

5. TRANSPORT

For transport and distribution of new product L-carnitine is used method of Traveling Salesman Problem (TSP) for routing on eastern and western parts of Macedonia. With comparison and analysis of the mentioned method or technique we'll provide conclusion for most adequate or most optimal routing for distribution and transport of the products.

Travelling sales procedure (TSP).The optimal solutions of the travelling sales procedure are based on the mathematical programming. However, in the reality, all optimal solution in the *TSP* the problems aren't solved optimally. For the big or complex problems, one or more exact solutions is impossible to reach, but there are techniques and principles for adequate programming. Two techniques generally are used for the *TSP* existing problems: *Nearest neighbor procedure* and *Clark and Wright savings heuristic.* (Frederick E. Webster [5], C. Haksever *et al.* [1]).

Nearest neighbor procedure. The procedure creates a tour according to the distance by driving from the last visited node to the nearest neighbor node in the network. In this case, the technique is very simple, but there is unpunctuality. In the Table 1 are showed distances between the cities where is done distribution of the new domestic energetic product L-carnitine and on the graphic views are shown nodes, or cities for the distributeon of the energetic product L-carnitine, D. Krstev [2].

In the regional distribution network in the eastern part of the Republic of Macedonia are following distributors and sub: (2) Kumanovo, (3) Kriva Palanka, (4) Veles, (5) Štip, (6) Delčevo and (7) Strumica.

Considering solutions for vehicle routing from the above figures it's possible to create complete tour 1→2→4→5→7→6→3→1 with length with 535 km. As this method do not approach optimal tour value, we'll repeat screening the network trying to find better tour, for example 1→4→6→ 7→5→3→2→1. The total distance from this tour will be 461 km, instead the previous distance from 535 km, or the difference from 48 km.

TSP Solver and Generator. By means of the applicative software it's possible to optimize TSP procedure, providing the appropriate procedure for optimal transport decision of the energetic new product L-carnitine in the region of the Eastern part of the Republic of Macedonia. The Figure 1 has showed distances between cities where product are distributed from the Koding-Skopje enterprise..

Table 1

Table with the shortest distances between cities (distances in km)

		Skopje	Kumanovo	Kriva Palanka	Veles	Štip	Delčevo	Strumica	Prilep	Bitola	Ohrid	Kruševo	Gostivar	Tetovo	Kičevo
(1)	Skopje	/	39	99	50	91	168	154	131	176	174	159	67	44	112
(2)	Kumanovo	39	/	60	55	66	145	131	135	171	214	162	107	82	152
(3)	Kriva Palanka	99	60	/	116	90	151	156	190	236	273	225	166	141	211
(4)	Veles	50	55	116	/	40	109	113	79	120	180	111	110	85	156
(5)	Štip	91	66	52	40	/	83	66	119	150	215	151	157	128	181
(6)	Delčevo	168	145	151	109	83	/	85	188	228	294	219	230	205	252
(7)	Strumica	154	131	156	113	66	85	/	134	175	237	166	221	191	226
(8)	Prilep	131	135	190	79	119	188	134	/	47	106	32	108	132	62
(9)	Bitola	176	171	236	120	150	228	175	47	/	66	52	124	146	78
(10)	Ohrid	174	214	273	180	215	294	237	106	66	/	138	107	132	61
(11)	Kruševo	159	162	225	111	151	219	166	32	52	138	/	140	164	62
(12)	Gostivar	67	107	166	110	157	230	221	108	124	107	140	/	24	46
(13)	Tetovo	44	82	141	85	128	205	191	132	146	132	164	24	/	70
(14)	Kičevo	112	152	211	156	181	252	266	62	78	61	62	46	70	/

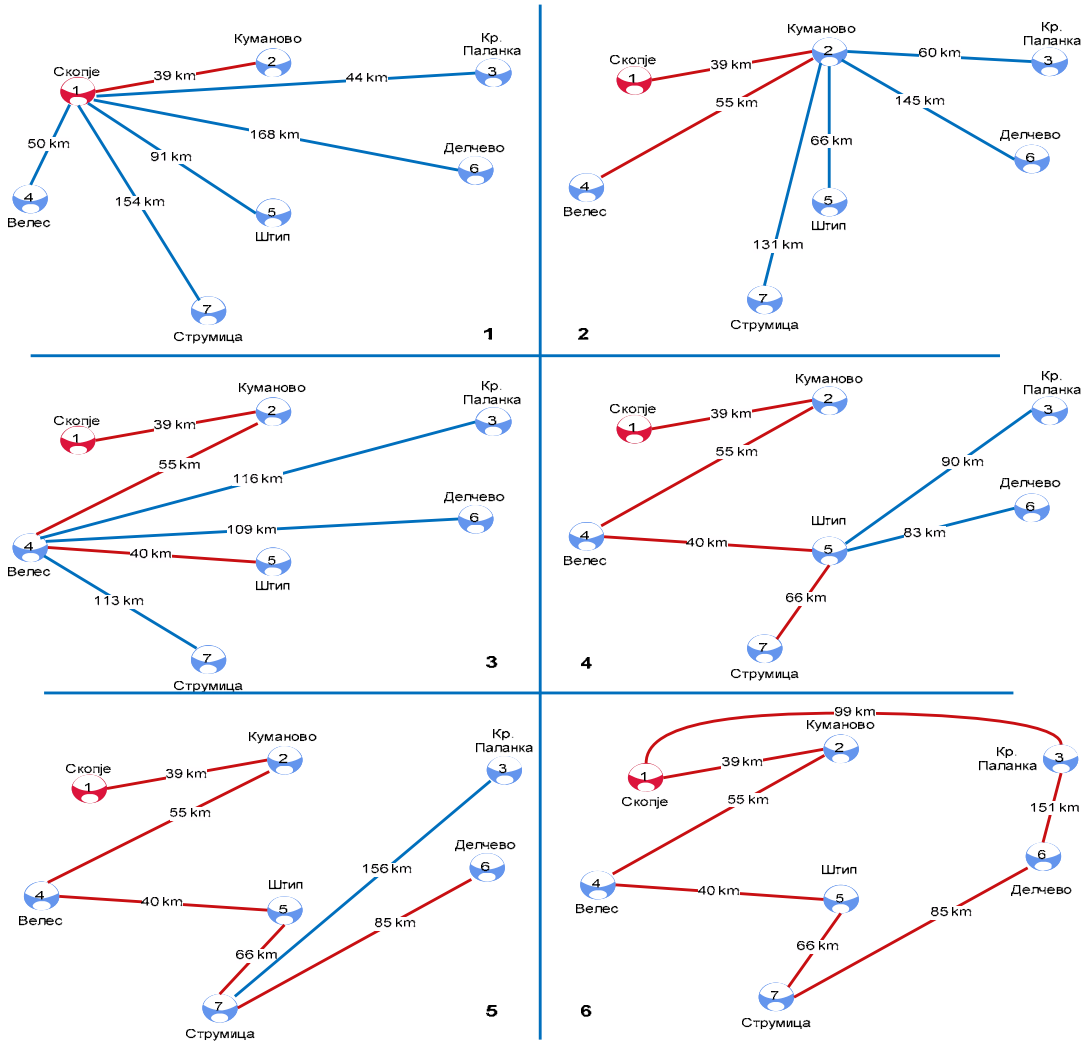

Fig. 1. Regional distribution network in eastern part of the Republic of Macedonia using the TSP

The results of the software decision of the *TSP Solver and Generator* are shown on the Figures 2 and 3.

The obtained result applying *TSP Solver and Generator* has confirmed the optimal solution, confirming the possible optimum solving, creating the route 1→4→6→7→5→3→2→1 with 461 km.

In the regional distribution network by parts or destinations in the western part of the Republic of Macedonia are presented by following distributors and subdistributors in the following towns: (8) Prilep, (9) Bitola, (10) Ohrid, (11) Kruševo, (12) Gostivar, (13) Tetovo and (14) Kičevo.

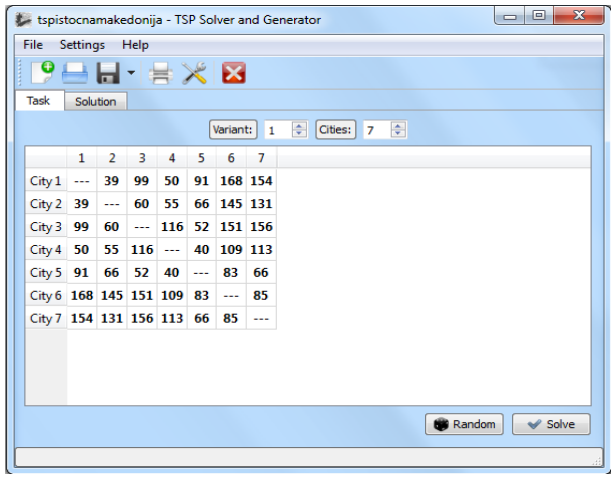

Fig. 2. TSP Solver and Generator

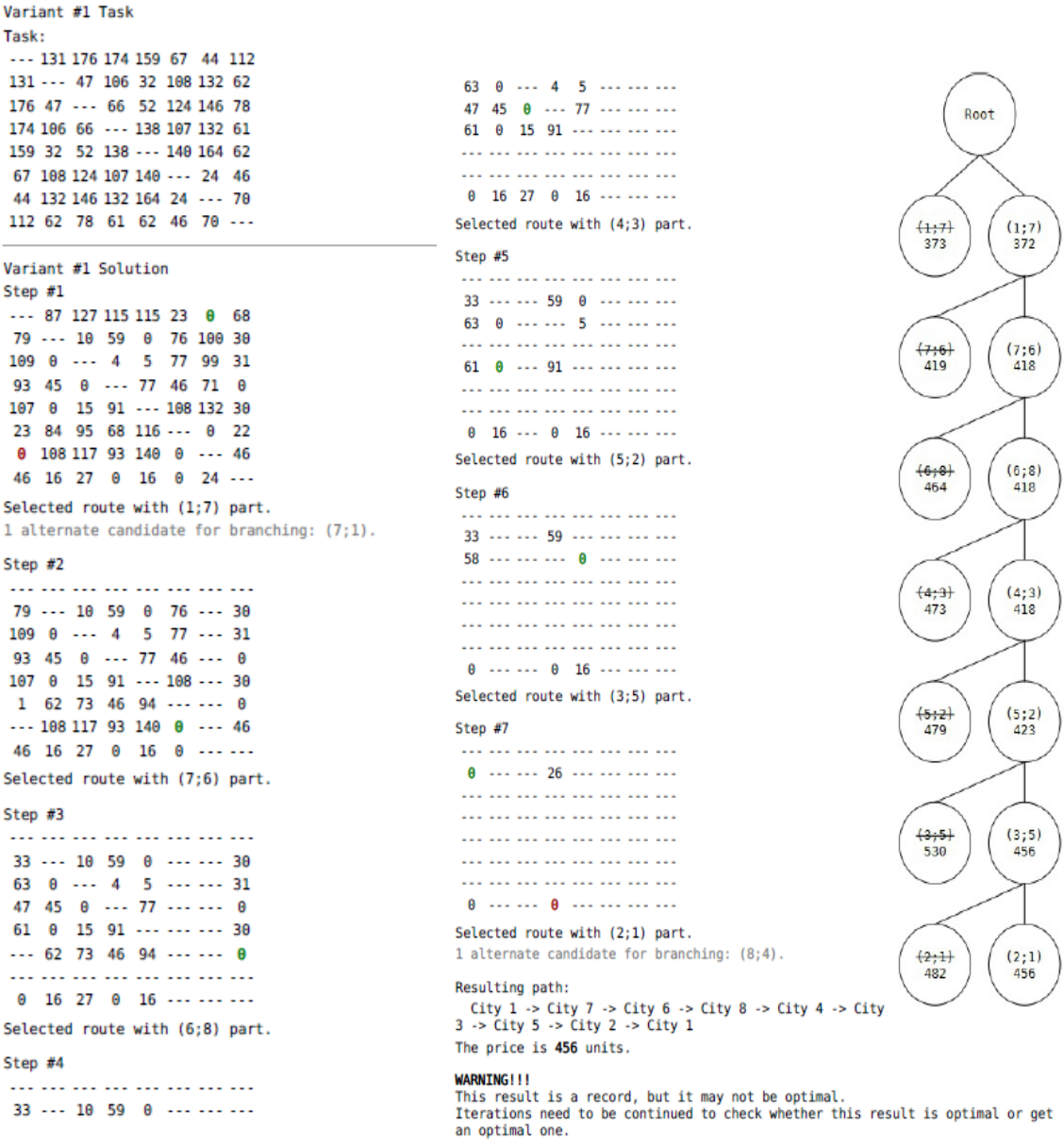

Fig. 3. Solution using solver

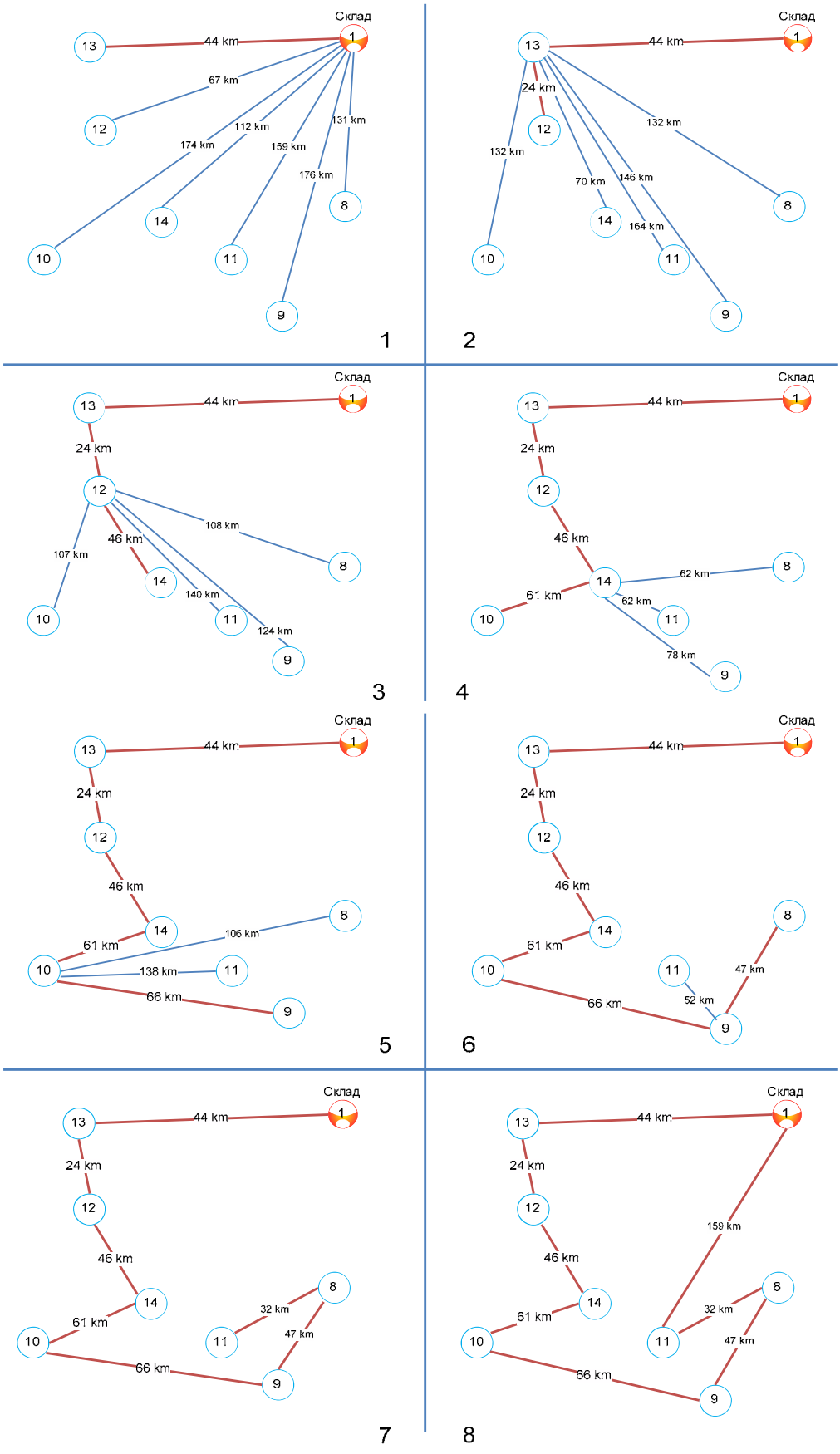

Fig. 4. Regional distribution network of westernpart of the Republic of Macedonia with TSP

Considering the obtained solutions for vehicle routing from the Figure 4 it's evidently to create complete tour 1→13→12→14→10→9→8→11→1 which length is 479 km. But, knowing that this method don't approach optimal value of the tour, for the second time we'll repeat the network trying to find better tour, for example 1→13→12→14→10→9→11→8→1. The total distance of this tour will be 456 km, instead the previous distance of 479 km, or the difference of 23 km.

TSP Solver and Generator. By means of the applicative software it's possible to optimize TSP procedure, providing the appropriate procedure for optimal transport decision of the energetic new product L-carnitine in the region of the western part of the Republic of Macedonia. The Figure 4 has showed distances between cities where product are distrubuted from the Koding-Skopje enterprise.

The results of the software decision of the *TSP Solver and Generator* are shown on the Figures 5 and 6.

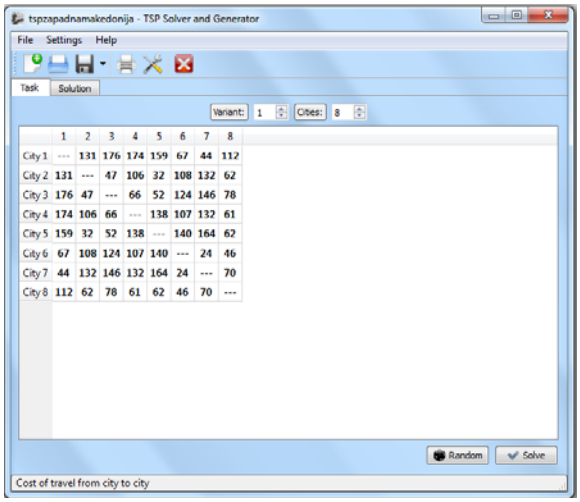

Fig. 5. TSP Solver and Generator

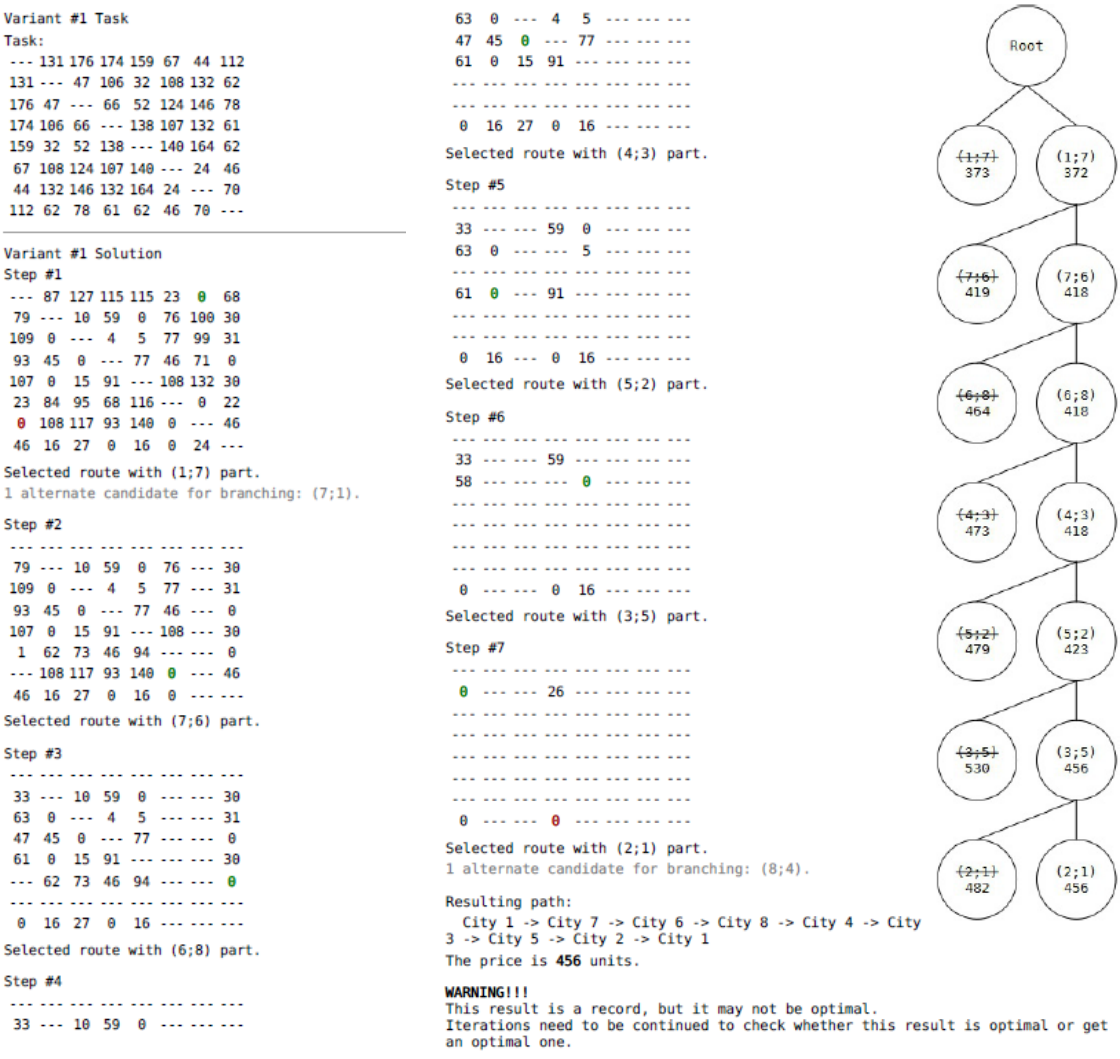

Fig. 6. Solution using solver.

The obtained results by applying the *TSP Solver and Generator* confirm the optimal decision, obtaining the possible route 1→13→12→ 14→10→9→11→8→1 with 456 km.

6. CONCLUSIONS

For transport and distribution of new product L-carnitine, Nicholas Dege [6], is used method of Traveling Salesman Problem (TSP) for routing on eastern and western parts of Macedonia. With comparison and analysis of the mentioned method or technique it's possible conclusion for most adequate or most optimal routing for distribution and transport of the product. The obtained result applying *TSP Solver and Generator* has confirmed the optimal solution, confirming the possible optimum solving, creating the route 1→4→6→7→5→3→2 →1 with 461 km. The obtained results by applying the *TSP Solver and Generator* confirm the optimal decision, obtaining the possible route 1→13→12 →14→10→9→1→8→1 with 456 km.

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[1] G. Vrtanoski, V. Dukovski, K. Yamaguchi: Use of polymer concrete for construction materials, *Proc. Fac. Mech. Eng, – Skopje,* **21**, 1, 43–48 (2002).

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[3] M. Golay, in: *Gas Chromatography*, D. Desty, ed. Butterworths, London, 1958, p. 36.

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