COMMUNICATIONS

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Dear reader,

The 9th International scientific conference TRANSCOM 2011 was held in the University of Zilina, Slovakia, in June 2011.

The main purpose of the conferences TRANSCOM organised regularly every other year since 1994 is a presentation of scientific works (from the fields of transportation, telecommunications, mechanical, electrical, civil, security, forensic engineering and social sciences) of young research workers including PhD students up to the age of 35 from universities, scientific institutions and industry.

More than 448 contributions were published in 9 proceedings of the conference TRANSCOM 2011 (158 contributions were from abroad, Czech Republic, France, Germany, Hungary, Italy, Poland, Romania, Russia, Slovenia, 11 were from the universities of the Slovakia and 279 contributions were from the University of Zilina).

I should express my gratitude to all participants for contributing to the TRANSCOM 2011 and to the TRANSCOM 2011 scientific committee including organizing committee members for cooperative spirit, motivation and enthusiasm.

The 10th International Scientific Conference TRANSCOM 2013 (jubilee) will be held in the University of Zilina, Slovakia, in June 2013.

This volume of the Communications is devoted to the selected contributions (recommended by the scientific committee) of the 9th International scientific conference TRANSCOM 2011, Zilina, Slovakia.

Otakar Bokuvka

Pavol Rafajdus – Peter Sekerak – Lukas Kalamen – Valeria Hrabovcova – Hao Chen *

STATIC AND DYNAMIC ANALYSIS OF LINEAR SWITCHED RELUCTANCE MACHINE

This paper deals with the static and dynamic analysis of the Linear Switched Reluctance Machine (LSRM). The static parameters are investigated by means of Finite Element Method (FEM) for real LSRM and also for its optimized construction topology, where the air gap and mover dimensions are changed. The calculated static parameters are inputs into dynamic mathematical model of the LSRM. This model is simulated under Matlab/Simulink. The output values of the simulation are phase currents, voltages, flux linkages and total force in air gap of real and also optimized LSRM. The results comparison of the real and optimized LSRM is given.

1. Introduction

An optimization of electrical machines design is a topical task from the point of view of input electrical energy consumption (motoring mode) and production of electrical energy (generating mode) [1]. The main aim of the optimization is to increase efficiency of electrical machines and to decrease losses. The efficiency optimization of electrical machines can be carried out during their design. There are several methods for the design process, mainly the analytical calculation [2], [3]. A very useful tool for the design of electrical machines is Finite Element Method (FEM). This method is also convenient to calculate the parameters and performance of electrical machines [4]. The LSRM construction is very simple. Both stator and mover have salient poles and only the stator carries winding coils, which are suitably connected to create phases. The magnetic flux is provided by phase current to develop a reluctance force [1]. This machine can operate as a motor or a generator. The three phase basic structure of LSRM is shown in Fig. 1.

This paper is written in cooperation between the University of Žilina and the China university of Mining and Technology in Xuzhou, China, where the LSRM was developed and manufactured. This LSRM is optimized from the point of view of power density, volume and electromagnetic force maximal value. In Fig. 2 there is shown a real prototype of the LSRM where the moving and static parts are separated for illustration. The LSRM from Fig. 2 is analyzed by means of FEM, especially with the FEMM 4.2 software using planar 2D system to calculate static parameters of the real and optimized LSRM, mainly phase inductance, electromagnetic force and flux linkage, needed for a deeper analysis of its performances during dynamic simulation and analysis. The static parameters mentioned above were calculated for different phase current and mover position.

On the base of this analysis, some construction optimizations are carried out. It means that the air gap δ and mover pole height h_m are changed (see Fig. 1). The air gap length in the real LSRM is 2 mm and it is changed from this value to 0.5 mm with the step 0.5 mm. The mover pole height hm is changed from 39 mm (real LSRM) to 20mm.

The calculated static parameters of the real and optimized LSRM are input values of LSRM mathematical model to simulate dynamic performances and parameters for constant or various speeds.

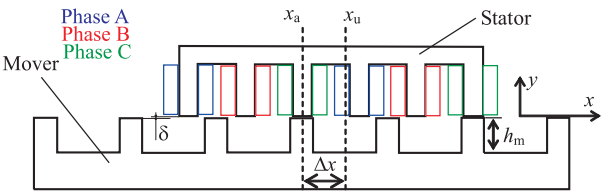

Fig. 1 The three phase LSRM

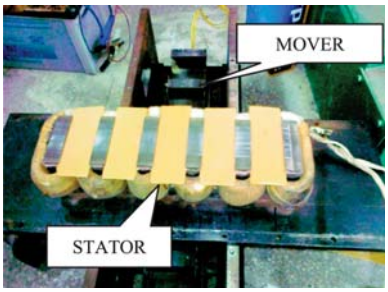

Fig. 2 The three phase LSRM prototype with separated stator and mover

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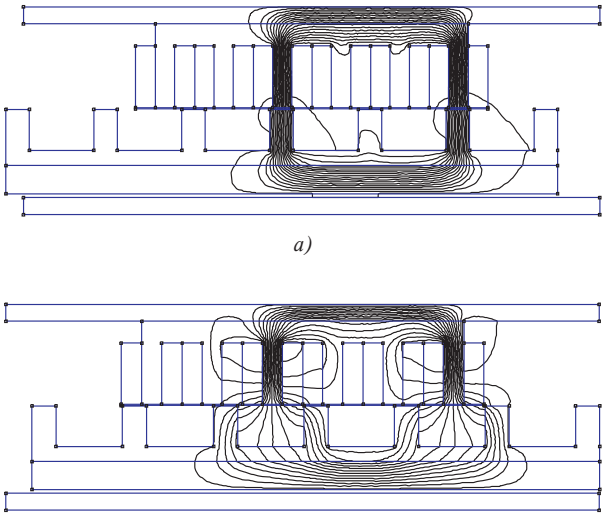
2. Static parameters analysis of the LSRM

For the FEM magnetostatic analysis the following input data are necessary: geometrical dimensions of the machine, current density of one phase, material constants (winding conductivity and relative permeability, B-H curve of LSRM ferromagnetic circuit material) and boundary conditions. The parametric model of LSRM was created in LUA script in the FEMM 4.2 software for more convenient calculation with lower time consumption. The LUA script also enables the LSRM model optimization (changes of the geometry of the machine) during the execution of the script.

The accuracy of the result depends on the size of FEM mesh and accuracy of the input parameters. In our model, 17.000 nodes were used. The calculation was carried out for each individual mover position and current under static condition. The mover position x was moved from aligned x_a to unaligned position xu with step of 0.5 mm and in each position the current was changed within its working range from 1 to 35A. In Fig. 3a the distribution of magnetic flux lines of LSRM for aligned position can be seen, in Fig. 3b for unaligned mover position. The phase current was kept constant 10A.



a)

b)

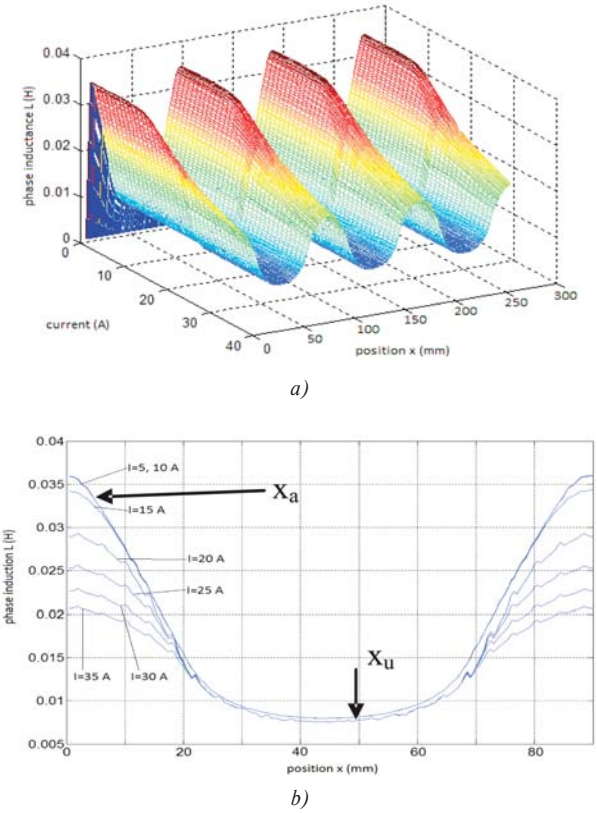
Fig. 3 The distribution of magnetic flux in the real LSRM for phase current 10 A, a) aligned mover position, b) unaligned mover position

2.1 Phase inductance calculation

The phase inductance $L = f(I, x)$ versus mover position for full current range is a static parameter which is needed in the LSRM mathematical model for dynamic simulations. The analysis was made for the whole working range of the real LSRM. The phase inductance profiles are shown in Fig. 4. The origin of the position axis is set to aligned position and the inductance decreases its value for each phase current until the mover and stator are not in unaligned position (Fig. 4b). The results are obtained by means of FEM for the LSRM in accordance with the following equation:

$$L = \frac{\int A \cdot JdV}{I^2}, \tag{1}$$

where A is magnetic vector potential, J is current density, V is volume and I is the phase current.



a)

b)

Fig. 4 The phase inductance for different phase currents and mover positions of the real LSRM: a) 3D view, b) 2D view

2.2 Electromagnetic force calculation

The electromagnetic force was also calculated by means of FEM. The static force characteristics were obtained for the whole working range. Maxwell's stress tensor prescribes the force per unit area produced by the magnetic field on a surface. The differential force produced at line l between mover and stator is:

$$F = l_{Fe}\frac{\mu_0}{2}\oint_l (H_n^2 - H_t^2)dl, \tag{2}$$

where n denotes the direction normal to the surface at the point of interest, B is flux density and H is intensity of magnetic field.

The calculated values of electromagnetic force in x direction are shown in Fig. 5a. For more complex analysis the average force F_{av} is necessary to be known. So the average force is given as:

$$F_{av} = \frac{1}{\Delta x}\int_{x_a}^{x_u} F\,dx\,. \qquad (3)$$

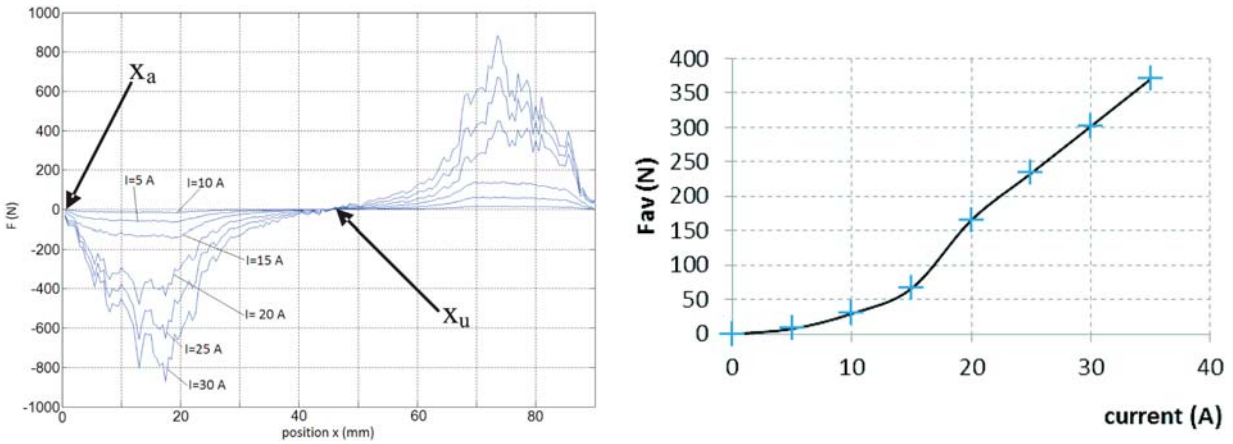
where Δx is defined as $\Delta x = x_a - x_u$ and it is the difference between aligned mover position x_a and unaligned mover position x_u. In this case the difference is 45 mm. The phase current was kept constant I = 5, 10, 15, 20, 25, 30, 35 and average electromagnetic force for LSRM is shown in Fig. 5b, calculated for interval Δx.

2.3 Optimization of the LSRM construction

As it has been mentioned above, optimization of the LSRM construction was carried out. In the first step, the air gap δ was changed between stator and mover (see Fig.1) from real size 2 mm to 0.5 mm. The phase current was kept constant I = 25 A, which is the rated value. The static parameters were calculated by means of FEM, mainly phase inductance and electromagnetic force in the air gap, which are needed for the dynamic mathematical model. These static parameters can be seen in Fig.6.

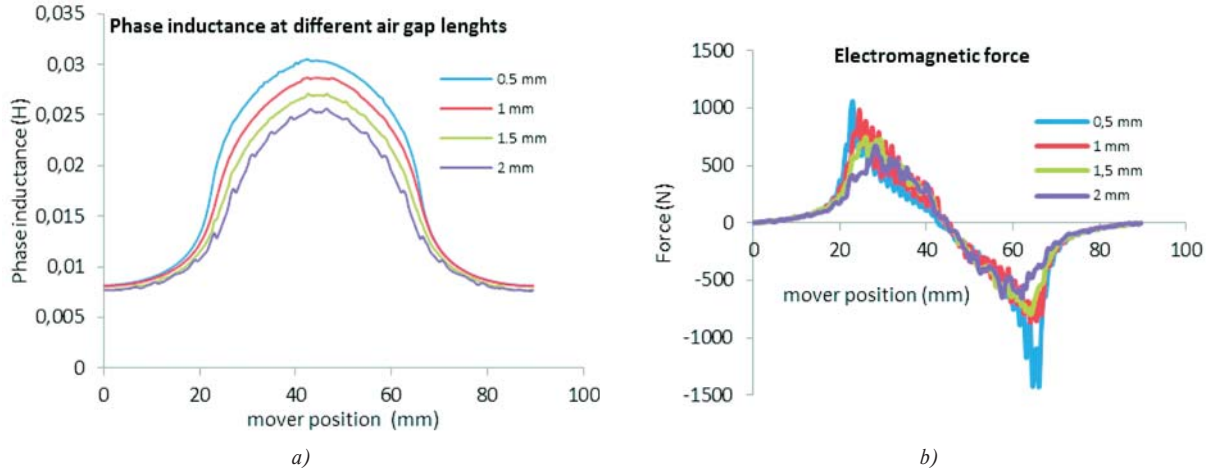
In the second step, the mover pole height hm (see Fig.1) was changed from its real size of 39 mm up to 20 mm. The phase current was kept constant I = 25 A and air gap was also constant 0.5 mm. The phase inductance and electromagnetic force were also calculated by means of FEM. These static parameters can be seen in Fig. 7.

For comparison, in Fig. 8 are shown behaviors of average electromagnetic force values Fav for both of optimizations: different air gap lengths (see Fig. 8a) and different mover pole heights (see



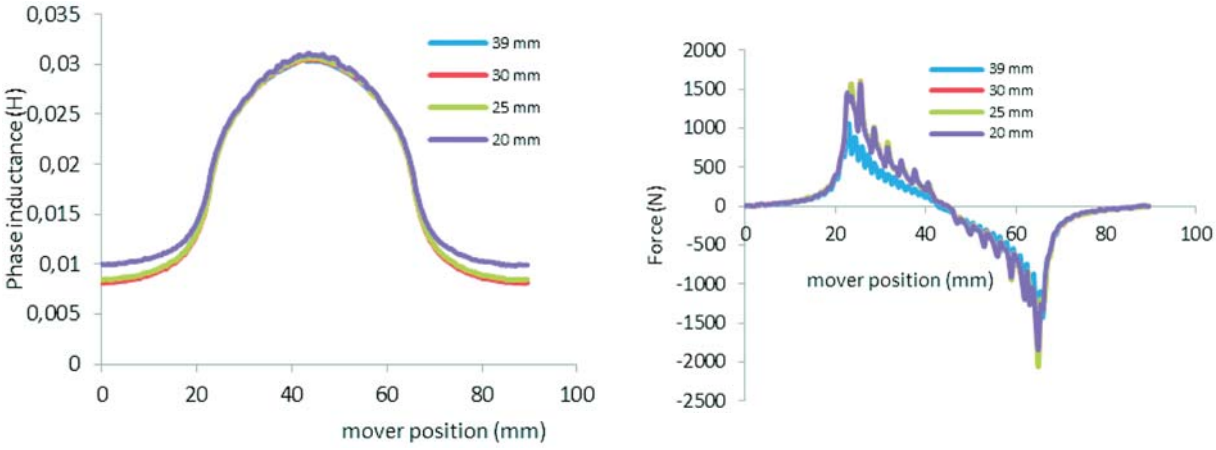
a) *b)*

Fig. 5 The LSRM electromagnetic force of the real LSRM: a) static curves, b) average forces



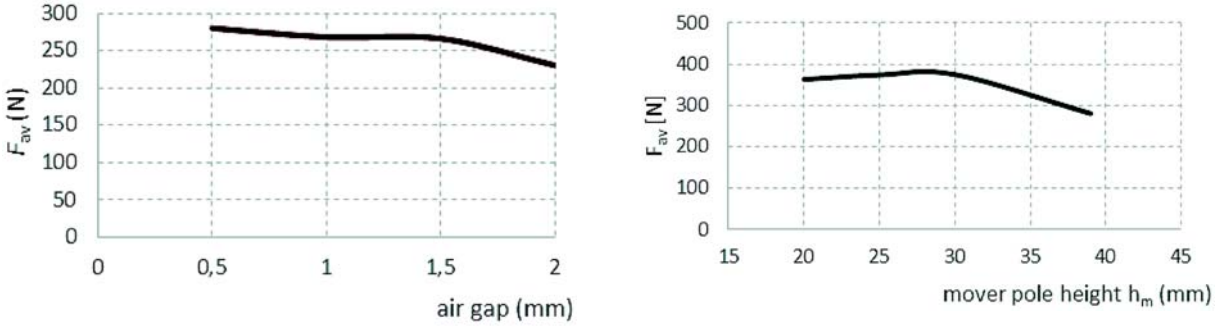
a) *b)*

Fig. 6 The LSRM static parameters obtained by means of FEM for various air gap lengths, a) phase inductance, b) electromagnetic force



a) *b)*

Fig. 7 The LSRM static parameters obtained by means of FEM for various mover pole heights, a) phase inductance, b) electromagnetic force



a) *b)*

Fig. 8. The LSRM average electromagnetic force, a) for various air gap lengths, b) for various mover pole heights

Fig. 8b). As it can be seen from these figures, the maximal average electromagnetic force 375 N occurs for air gap 0.5 mm and mover pole height 28 mm. In opposite, the lowest value of average electromagnetic force 235 N is for the real LSRM (see Fig. 2).

3. Dynamic Analysis of the LSRM

For the dynamic analysis, the nonlinear mathematical model was used [8]. The phase current was calculated from the next equation:

$$\frac{di}{dt} = \frac{u - \left(R + \frac{dL(x,i)}{dx}\frac{dx}{dt}\right)i}{L(x,i)} = \frac{u - \left(R + \frac{dL(x,i)}{dx}v\right)i}{L(x,i)} \quad (4)$$

where the input voltage u was changed in accordance with the current regulator, R is the phase resistance obtained from measurement, L is phase inductance obtained from FEM and v is speed of the mover. The instantaneous force of one phase f was calculated from the 2D look up table by means of linear interpolation, because it is faster than to calculate it from equation. The values of 2D force table were obtained from FEM. The total instantaneous force of all phases is calculated as:

$$f = \sum_{j=1}^{m} f_j(x,i) \quad (5)$$

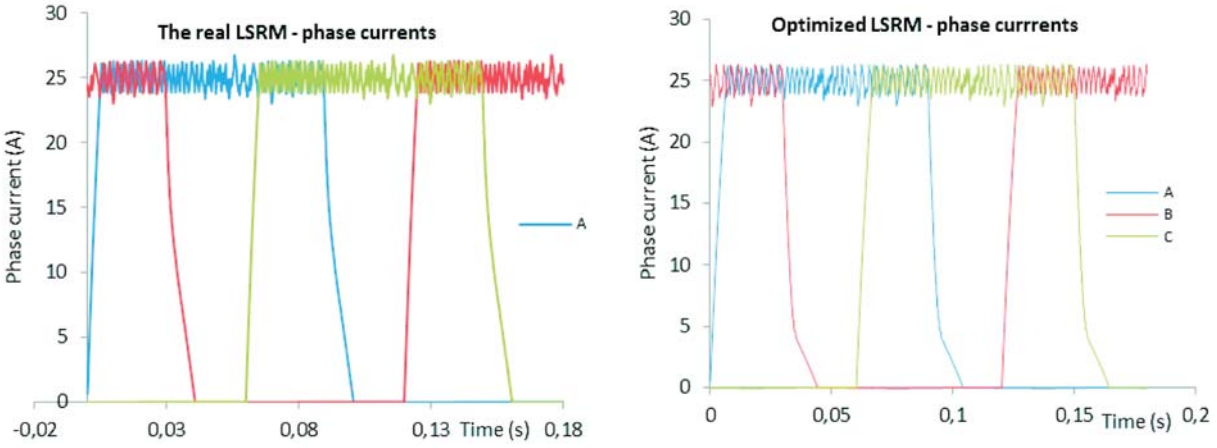
The real speed of the mover can be calculated from the equation:

$$\frac{dv}{dt} = \frac{1}{J}\left(\sum_{j=1}^{m} f_j(x,i) - f_{load}\right) \quad (6)$$

where J is the moment of inertia and fload is load force. Finally, the mover position is given as:

$$x = \int v\,dt \quad (7)$$

This mathematical model was simulated under Matlab/Simulink. The input parameters as phase inductance and force were taken from the static analysis for real LSRM and optimized LSRM (air gap 0.5 mm and mover pole height 28 mm). In accordance with the equation (7), the mover speed v started from 0 m/s to 1.5 m/s. From



a) *b)*

Fig. 9 The LSRM phase current waveforms, a) real, b) optimized

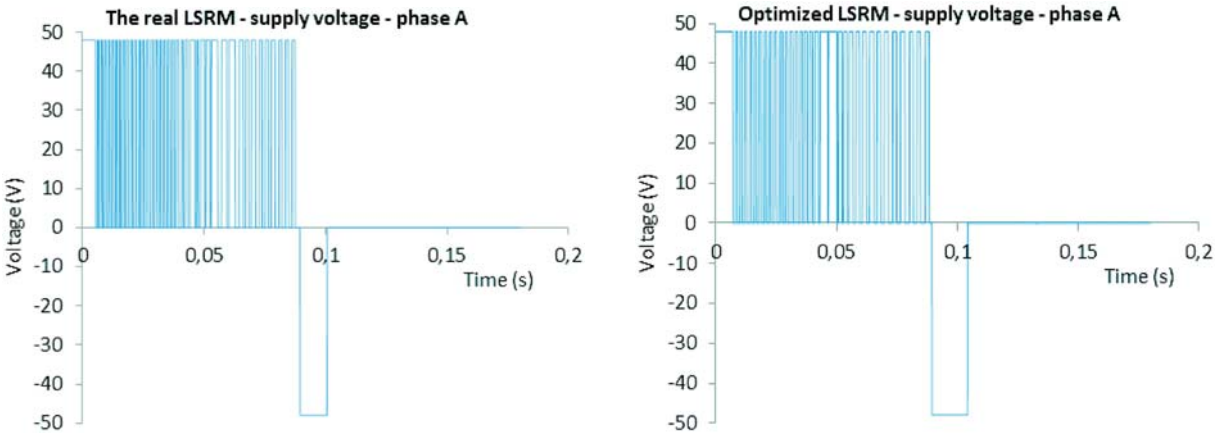


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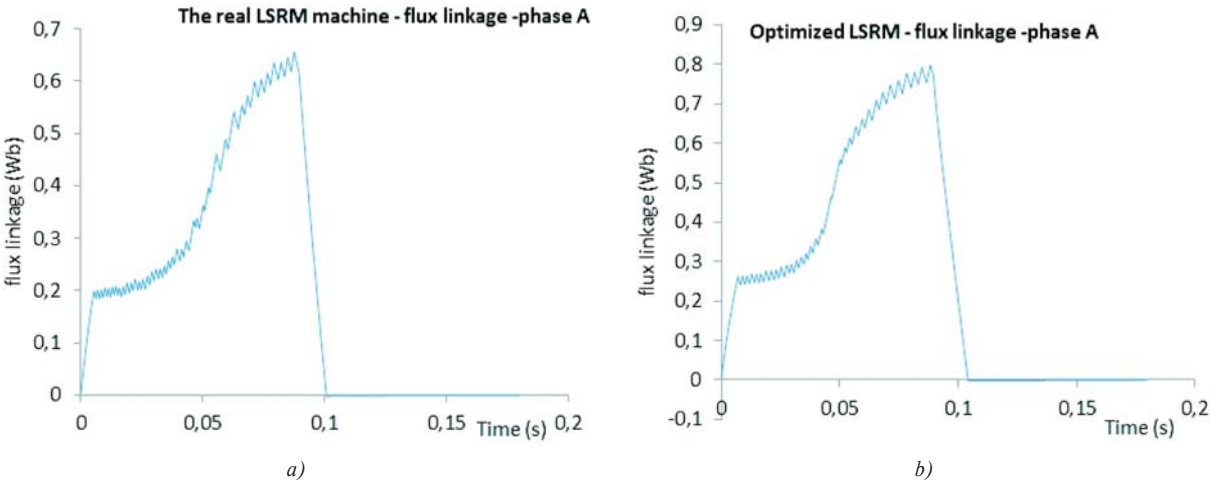
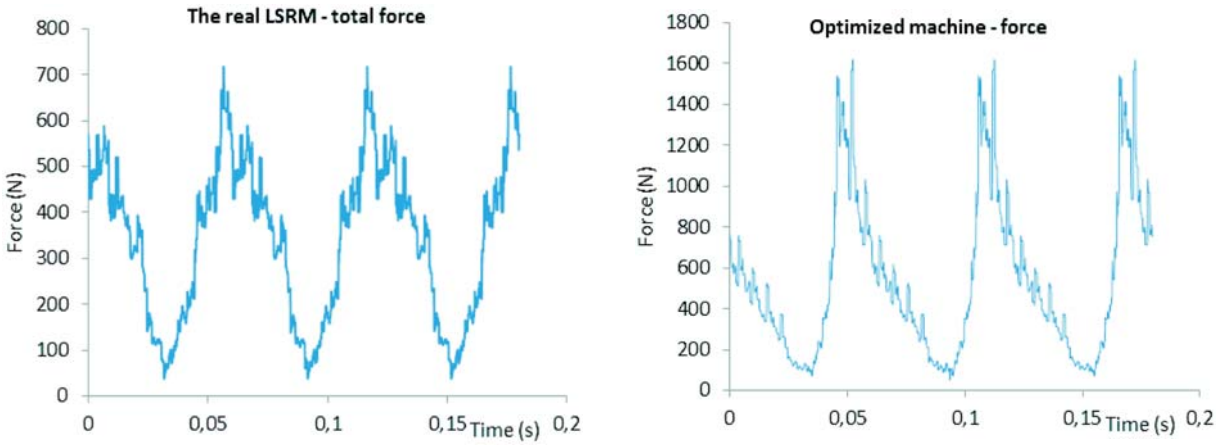
Fig. 10 The LSRM phase voltage waveforms, a) real, b) optimized



a) *b)*

Fig. 11 The LSRM flux linkage waveforms, a) real, b) optimized



a) *b)*

Fig. 12 The LSRM total electromagnetic force waveforms, a) real, b) optimized

this mathematical model and simulation system next waveforms were calculated: phase currents, phase voltage, flux linkage and instantaneous force. These waveforms were calculated for different speeds from 0 m/s to 1.5 m/s. The phase current was kept on reference current 25 A by the current regulator. The phase current waveforms, phase voltage waveforms, flux linkage and total force of the real and optimized LSRM can be seen in Figs. 9, 10, 11 and 12 respectively.

As it can be seen from Fig.12, the maximal value of optimized LSRM total force is higher than in the real original LSRM. In opposite, the force ripple of optimized LSRM is higher than in the real LSRM, which can be decreased by a next construction or control LSRM optimization.

4. Conclusion

The static parameters of the real and optimized LSRM were investigated by means of FEM. The phase inductance and force of the machine were calculated for each mover position and phase current. The average force was calculated and compared with the LSRM optimized construction. The mathematical model was described and solved to obtain dynamic waveforms of phase currents, voltages, flux linkage and total force. The investigated parameters will be compared with measurement ones in a future work. It is obvious that there are still some imperfections in the machine design and hence our future effort will be set on the efficiency improvement of the LSRM.

Acknowledgement

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IDENTIFICATION OF THE COMBUSTION ENGINE RESISTANCE TO MOTION TORQUE COMPONENTS

Identification of the combustion engine resistance to motion is necessary in all investigations aimed at limiting frictional losses. Despite many attempts to measure the frictional resistance components, there are still no functional test beds that would allow to take measurements of frictional force or frictional torque in particular units. Most often the mean value of the torque for one or even two full revolutions of the crankshaft is determined. For many reasons it is more convenient to determine the resistance to motion torque of the combustion engine with an external drive but unfortunately, the torque from the external drive is disturbed by torsional vibration. There is at least a theoretical possibility of separating the torque generated by vibration from the raw measuring signal. In the paper, the results obtained as well as selected problems of such separation are presented.

Keywords: internal combustion engine, coupling torque, harmonic components, proper vibration of the crankshaft

1. Introduction

Identification of the combustion engine resistance to motion is necessary in all investigations aimed at limiting frictional losses. Despite many attempts to measure the frictional resistance components, no functional test beds that would allow to take measurements of frictional force or frictional torque in particular units have been constructed yet. Usually it is the value of the coupling torque of the engine with the power receiver that is the basic measurement during the combustion engine investigations. Most often the mean value of the torque for one or even two full revolutions of the crankshaft is determined. The test bench equipped with a torque sensor is shown in Fig. 1.

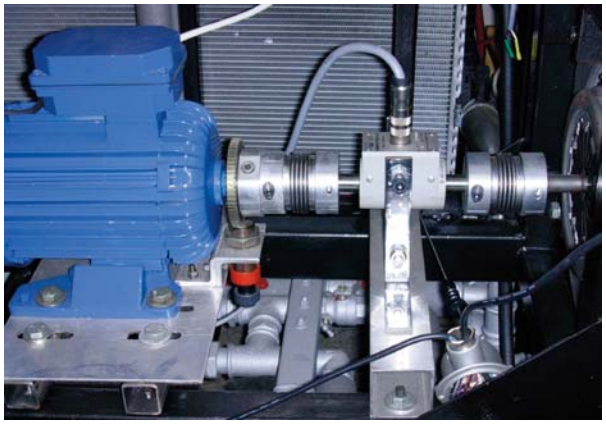

Fig. 1. The test bed of the two-cylinder combustion engine of a passenger car equipped with the measurement set for the instantaneous torque values

The resistance to motion torque of the combustion engine accompanies rotation of the crankshaft regardless of whether the engine is in normal operation or if it is revolved by the external engine. For many reasons, it is more convenient to determine the resistance to motion torque of the combustion engine with the external drive. Unfortunately, the torque from the external drive is disturbed by torsional vibration because the rotor of the driving engine creates the vibratory unit with the tested engine crankshaft. For this reason, the torque sensor placed between the rotor and the crankshaft measures the torque which is the sum of the resistance to motion torque of the investigated engine and the torque generated by vibration. Because in a longer period of time the frequency of the torque generated by vibration is usually not the exact multiplicity of the driving engine rotational frequency, there is at least a theoretical possibility of separating the torque generated by vibration. In the paper, the results obtained as well as selected problems of such separation are presented.

2. Torque transmitted from the driving engine shaft to the crankshaft of the investigated combustion engine

In Fig. 2, the thinnest blue line presents the course of torque. It was measured on the test bed at 3000 rpm.

It can be noticed that the course of the measured signal is not repeatable in the following working cycles. The work character of the piston engine determines the periodicity formation of resis-

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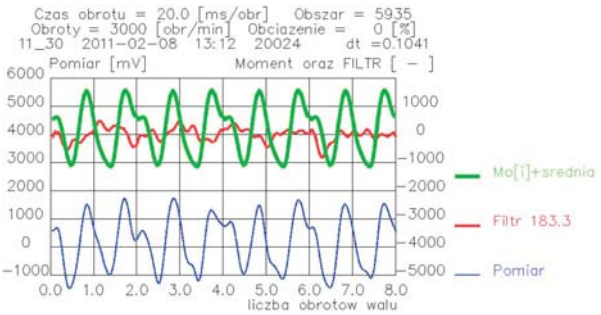

Fig. 2. The course of torque measured with the torque sensor – the thinnest blue line, torque obtained after excluding harmonic components which are the multiplicity of the 720 degrees working cycle – the thickest green line, the sum of harmonic components excluded from the measured signal – red average thickness line. Key: Czas obrotu- revolution time, obszar – area, obroty- revolutions, obciążenie – load, pomiar – measurement, Moment oraz filtr – torque and filter, liczba obrotów wału – crankshaft revolutions

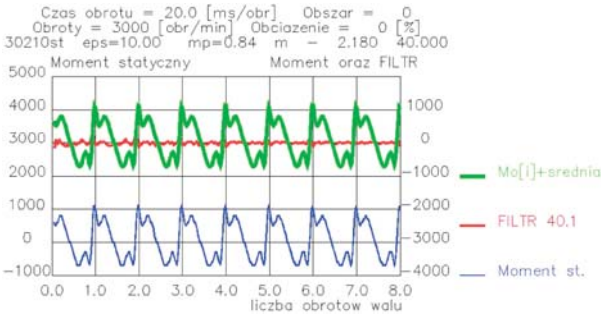

Fig. 3. The course of the static torque obtained with use of a computer simulation – the thinnest blue line, The course of torque obtained after excluding harmonic components which are the multiplicity of the 720 degrees working cycle – the thickest green line, the sum of harmonic components excluded from the measured signal – red average thickness line

tance to motion components. These components are mainly: the resistance of compression, resistance of inertia, frictional resistance. As a result, the coupling torque of the drive with the engine on the test bed shown in Fig. 1 should repeat itself in cycles of two revolutions of the crankshaft. The only component of the coupling torque whose frequency is different from the shaft revolutions frequency is the frequency of various proper vibration forms. Theoretically it is possible that the frequency of one of the forms is close to the shaft rotational speed but this phenomenon is easy to detect.

What results from the described regularity is that the harmonic different from the multiplication of shaft revolutions frequency can be excluded. As a result of performing the described operation, the course of torque was obtained and is pointed out in Fig. 2 with the thickest green line. Additionally, the red line presents the summary course of excluded harmonic components.

3. Comparison of the revised resistance to move torque with the calculated torque of the investigated engine

Making the static course – that is excluding the shaft proper vibrations- of the resistance to move torque is a typical operation connected with designing a new engine. Despite omitting the shaft proper vibration, the static course of torque allows to estimate energetic characteristics of the new engine but such course is of little use in strength calculations. However, in order to evaluate the obtained course of the revised resistance to move torque which is shown in Fig. 2, a comparison with the calculated statistic course shown in Fig. 3 was made.

As it can be noticed there are some distinctions between the character of the modified measured course (Fig. 2) and the character of the simulated course (Fig. 3). It mainly concerns the repeatability of courses. The measured signal repeats itself every two revolutions and the simulated signal recurs every single revolution. Because courses concern the two-cylinder four-stroke engine, the repeatability of static course is obvious. But the results of the revised measurements do not confirm the seemingly obvious computer simulation results. It is likely to result from a greater torsional deflection of the crank more distant from the torque sensor.

4. The influence of engine speed accuracy on excluding proper vibration components from the measured signal

The presented method of revising the measured signal of the coupling torque is fraught with many errors. The main problem is the precise determination of the periodical torque components frequencies resulting from the engine function and not from the proper vibration. In order to determine how the engine speed measurement error influences the obtained revised signal, an analysis

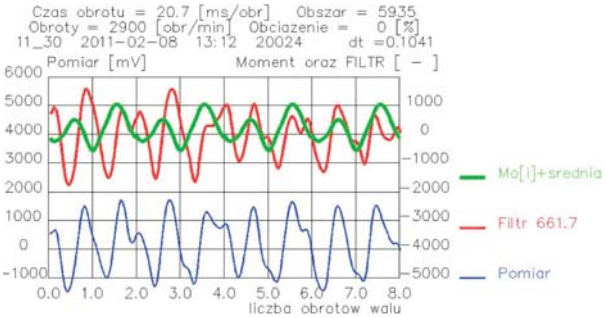

Fig. 4. The torque course from torque sensor – the thinnest blue line, The course of torque obtained after excluding harmonic components which are the multiplicity of the 720 degrees working cycle – the thickest green line, the sum of harmonic components excluded from the measured signal – red average thickness line. The assumed engine speed is 3 % less than the actual engine speed

was made which was analogous to the one presented in Fig. 2 but with the engine speed incorrectly assumed at 2900 rpm instead of 3000 rpm. The obtained revised course is presented in Fig. 4.

It is easy to notice that if the rotational speed is 3 % less than the actual engine speed, the revised course differs from both the actual engine speed revised course (Fig. 2) and the course obtained with use of computer simulations (Fig. 3).

It is only if the actual engine speed dispersion is less than 0.5 % from the assumed for revising that it basically does not influence the correctness of the realized revising (Fig. 5).

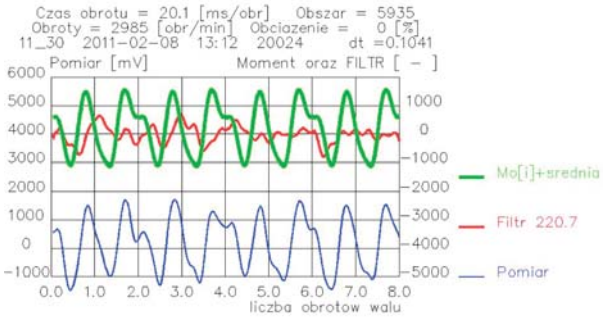

Fig. 5. The torque course from torque sensor - the thinnest blue line, the course of torque obtained after excluding harmonic components which are the multiplicity of the 720 degrees working cycle - the thickest green line, the sum of harmonic components excluded from the measured signal - red average thickness line. The assumed engine speed is 0,5 % less than the actual engine speed

5. Repeatability of courses

The results of torque measurements presented earlier are adequate to the conditions in which the component generated by inertia forces has a substantial share and therefore at a high engine shaft speed. In case of lower values of the rotary speed close to the neutral run, there occur components in the signal of the resistance to motion torque which significantly disrupt the anticipated torque course. Apart from two fundamental components (the torque generated by gas and friction forces) there occurs a relatively strong torque generated by vibrations in the combustion engine – electric motor unit. In the case when the vibrations torque component frequency is not the multiplicity of rotations frequency, the applied computer program allows to exclude such a component. However, if the vibrations component frequency is close to the multiplicity of rotations frequency, such a component is difficult to identify since it can be generated by both friction and vibrations. However, the hitherto conducted research shows that usual vibrations generate high frequencies, whereas friction is quite well modeled by low frequencies represented by the harmonic lower than 33rd order for a two-cylinder four-stroke engine. The correctness of the presented thesis is documented by the courses shown in Figs. 6 – 9.

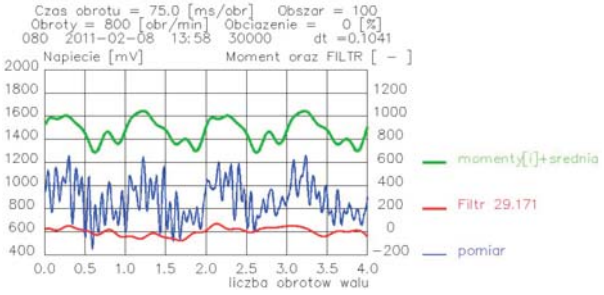

Fig. 6. The course of torque measured with the torque sensor - the thinnest blue line, torque obtained after excluding harmonic components which are the multiplicity of the 720 degrees working cycle - the thickest green line, the sum of harmonic components excluded from the measured signal - red average thickness line; the courses obtained from measurement point nr 100

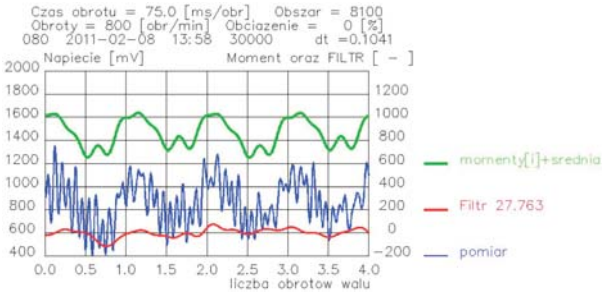

Fig. 7. The course of torque measured with the torque sensor - the thinnest blue line, torque obtained after excluding harmonic components which are the multiplicity of the 720 degrees working cycle - the thickest green line, the sum of harmonic components excluded from the measured signal - red average thickness line; the courses obtained from measurement point nr 8100

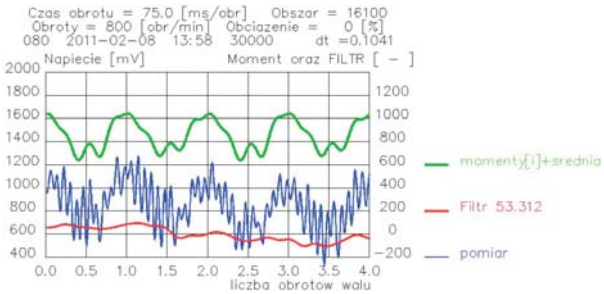

Fig. 8. The course of torque measured with the torque sensor - the thinnest blue line, torque obtained after excluding harmonic components which are the multiplicity of the 720 degrees working cycle - the thickest green line, the sum of harmonic components excluded from the measured signal - red average thickness line; the courses obtained from measurement point nr 16100

These figures present the unstable measured signal – the thinnest blue line and the sum of 32 harmonics – the green line.

In spite of the fact that the course in Fig. 7 was obtained with the delay of 8000 measuring points, and in Fig. 8 – of 16000 points, the obtained revised courses marked green are very similar. The performed reasoning shows that the revised courses mainly result from the influence of gas and friction forces. Since the gas forces result quite accurately from the realization of the thermodynamic cycle, one can easily subtract the torque generated by gas forces from the revised torque and obtain as a result a pure form of the torque generated by friction forces. One should emphasize that the presented reasoning is accurate under the condition of a precise repeatability of the revised torque, which is proven by Figs. 6–8.

In order to compare the obtained research results with the results of the computer simulation, a summary course of the torques generated by gas and inertia forces is presented in Fig. 9.

Therefore, the differences in the courses in Figs. 8 and 9 result from the omission of friction forces in the simulation.

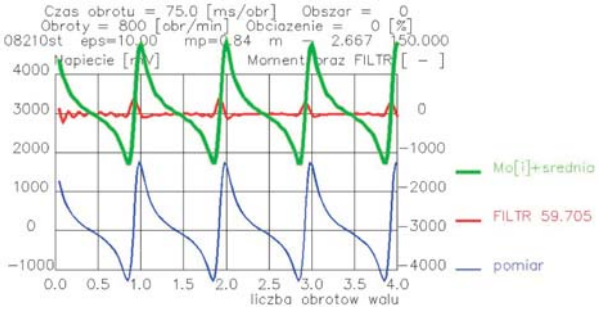

Fig. 9. The course of the static torque obtained in a computer simulation – the thinnest blue line, the course of torque obtained after excluding harmonic components which are the multiplicity of the 720 degrees working cycle – the thickest green line, the sum of harmonic components excluded from the signal of the computer simulation – red average thickness line; rotational speed – 800 [rpm]

6. Conclusion

The presented method of revising the measured resistance to motion torque of the combustion engine is necessary to determine instantaneous torque values, i.e. to evaluate the internal friction components in the combustion engine. This method requires the precise maintaining of a constant engine speed. It is recommended that the engine speed should be specified with the accuracy of not less than 0.5 %.

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Andrej Kovalcik – Emil Toporcer – Vladimir Hlavna *

FLOW MODELING IN AN EVAPORATOR OF A NONCONVENTIONAL ENERGETIC SYSTEM

An alternative cooling medium (lithium bromide liquid) flows in a cooling jacket of a combustion engine of a nonconventional energetic unit. The paper deals with a flow simulation of the working medium in the vaporization container of a cooling circuit of the nonconventional combustion engine. Consequently evaporation and thermal states at the atmospheric pressure above the nonconventional cooling liquid (solution LiBr - H2O) level in the evaporator are simulated. Limiting conditions for the functionality assurance of the cooling system of the nonconventional combustion engine were found by means of a simulation.

1. Introduction

A nonconventional cooling-combustion engine uses the part of energy bound in a cooling system of a combustion engine for production of the cooling output applicable in vehicles (see Fig. 1) [2].

An engine cooling liquid is replaced by mixture of the lithium bromide liquid with water [6]. The solved energetic system is defined in area of trigeneration systems. The mentioned system is a source of electrical energy, cold and heat. The engine used in the system is four stroke compression ignition engine Z8004 with rated power of 77 kW at 2200 min^{-1}. The heat produced by the engine cooling system is pulled into the absorption cooling equipment.

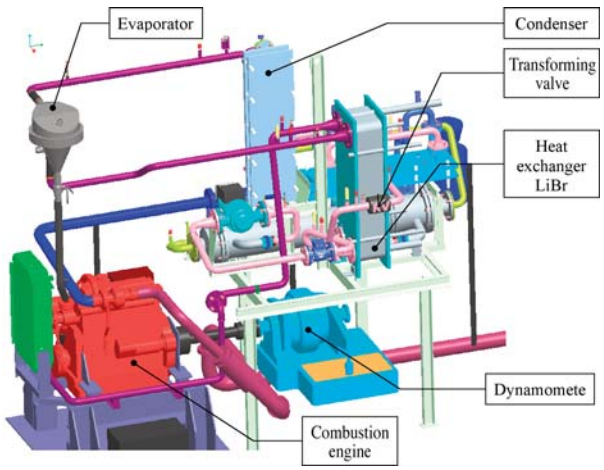

Fig. 1 Virtual model of the non-conventional energetic unit [2]

The article shows the flow simulation of the working medium in this structural shape of vaporization container of a cooling circuit of the nonconventional combustion engine. The problem with vaporization container was that the off-take wasn't able to take away the entire needed amount from the evaporator.

2. Definition of the model and the flow simulation

The CAD software used for the model creation is CATIA V5 [2]. The model of the whole evaporator can be seen in Fig. 2.

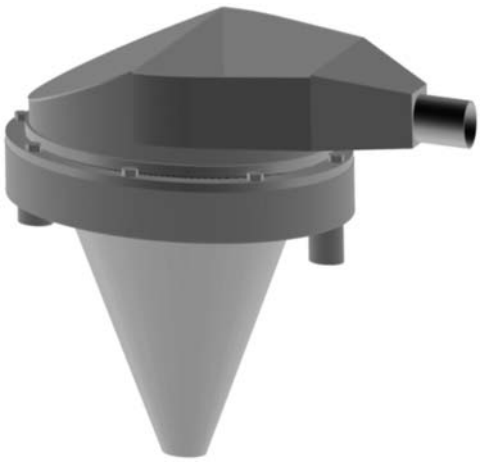

Fig. 2 CAD model of the evaporator

For the purpose of simulation we used only one half of this space because of the symmetry of the geometry which allows for

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decrease in the requirements for the used hardware and computational time.

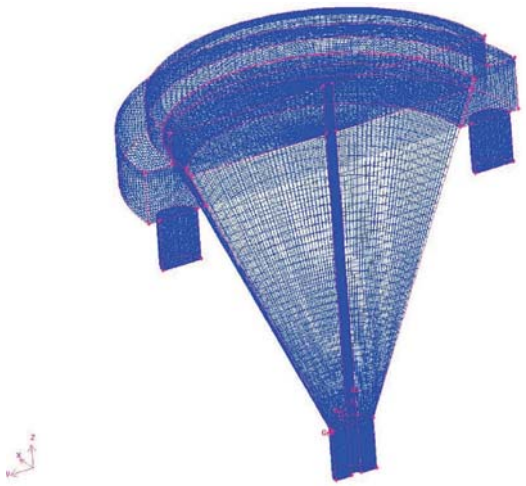
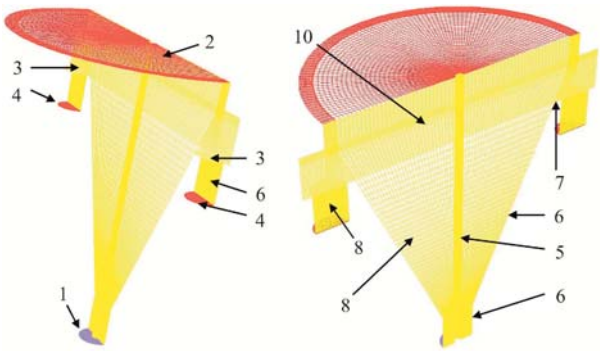


Fig. 3 View of the model of evaporator [5]

Fig. 3 shows the mesh in the area of the bottom outlet. Then the suitable types of boundary conditions are applied to the mesh model (see Fig. 4). The resulting mesh contains about 480 000 elements [5].



1-velocity inlet I, 2-pressure outlet I, 3-velocity inlet II, 4-pressure outlet II, 5-axis, 6-wall, 7-interface wall + velocity inlet II, 8-symetry

Fig. 4 Boundary conditions

Next step was the definition of the computational model. Values for the boundary conditions were set. The RNG $k-\varepsilon$ turbulent model was used for the flow simulation. This model is robust enough and suitable for the solution of turbulent flows and heat transfer [4]. The renormalized procedure consists of a gradual elimination of small turbulences. Equations of motion are transformed so that turbulent viscosity, forces and nonlinear members are modified. Assuming that the turbulences are related to dissipation ε, then, the turbulent viscosity μ, depends on a degree of turbulences and the RNG method constructs this viscosity with the help of iterative elimination of narrow bands of wave numbers. The following equation is used for the iterative process [1 and 5]:

$$\frac{d\mu_{eff}}{dl} = \frac{A_t \varepsilon l^3}{\mu(l)^2} \tag{1}$$

The RNG model derived by a statistical method, averaged, is formally of the same form as the classical $k-\varepsilon$ model. The equation for the transfer of motion is in the form:

$$\frac{\partial}{\partial t}(\rho\bar{u}_i) + \frac{\partial}{\partial x_j}(\rho\bar{u}_i\bar{u}_j) = \\ = \frac{\partial}{\partial x_j}\left[u_{eff}\left(\frac{\partial\bar{u}_i}{\partial x_j} + \frac{\partial\bar{u}_j}{\partial x_i}\right) - \left(\frac{2}{3}u_{eff}\frac{\partial\bar{u}_i}{\partial x_i}\right)\right] - \frac{\partial\bar{p}}{\partial x_i} + \rho g_i + F_i \tag{2}$$

and, subsequently, transport equations are used:

$$\frac{\partial}{\partial t}(\rho k) + \frac{\partial}{\partial x_j}(\rho\pi_j k) = \\ = \frac{\partial}{\partial x_j}\left(\alpha_k\mu_{eff}\frac{\partial k}{\partial x_j}\right) + \mu_t S^2 - \rho\varepsilon \tag{3}$$

$$\frac{\partial}{\partial t}(\rho\varepsilon) + \frac{\partial}{\partial x_j}(\rho\mu_j\varepsilon) = \\ = \frac{\partial}{\partial x_j}\left(\alpha_\varepsilon\mu_{eff}\frac{\partial\varepsilon}{\partial x_j}\right) + C_{1\varepsilon}\frac{\varepsilon}{k}\mu_t S^2 - C_{2\varepsilon}\rho\frac{\varepsilon^2}{k} - R \tag{4}$$

Time step was set to 0.001 s. The velocity in the inlet was set to 0.68 m.s^{-1}. Fig. 5 shows the level of the cooling liquid at the start of the simulation process (1 cm under the edge of the evaporator cone).

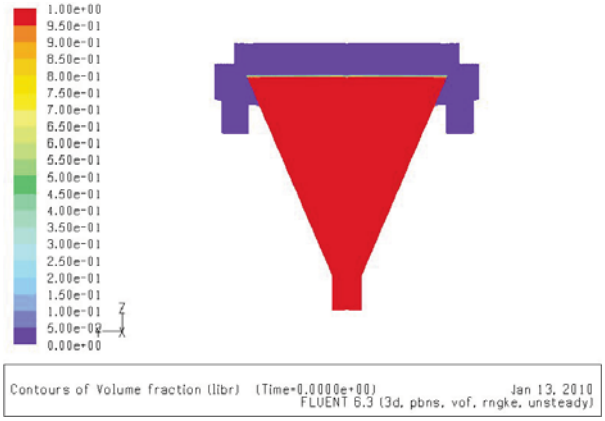


Fig. 5 Coolant level in the evaporator at the start of the simulation

3. Achieved results

The filling of the evaporator ring by the cooling medium is shown in Figs. 6, 7, 8 and 9. The off-take is able to take away the

entire needed amount from the evaporator. The simulation shows that the lithium bromide liquid starts to pour through the edge of the evaporator cone in the time of about 0.96 s after the initiation of the calculation. The starting cooling liquid level has the value of 1 cm under the edge of the evaporator cone. The value of 1 cm is used because of the decrease in the computational time.

The found value of 0.96 s valid for the 55 % lithium bromide liquid cannot be experimentally verified by means of simulation due

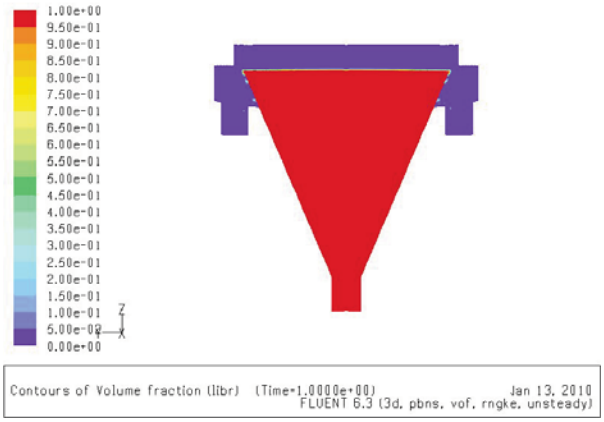


Fig. 6 Flow in the evaporator in the time of 1 s

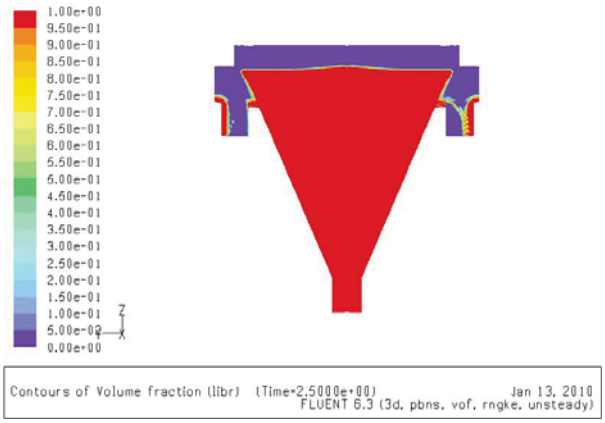


Fig. 7 Flow in the evaporator in the time of 2.5 s

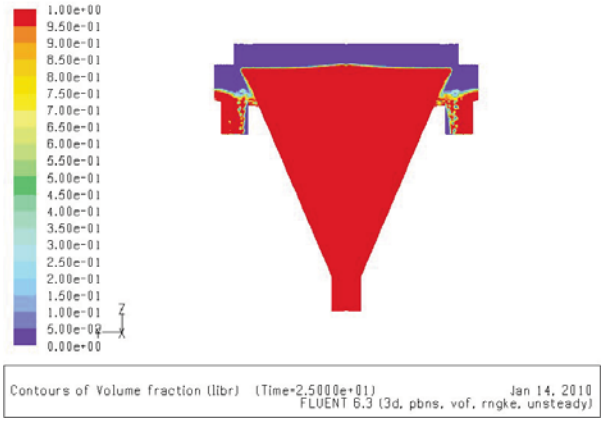


Fig. 8 Flow in the evaporator in the time of 25 s

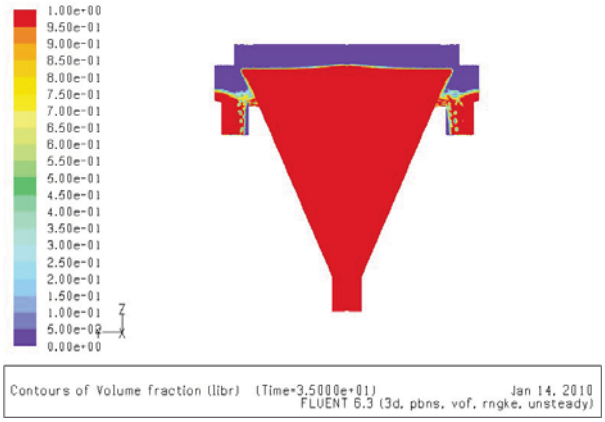


Fig. 9 Flow in the evaporator in the time of 35 s

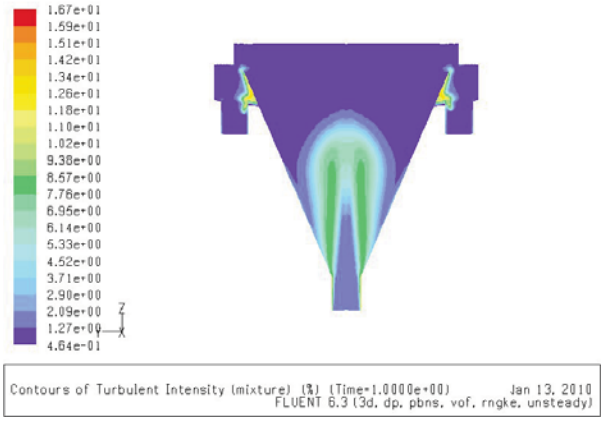


Fig. 10 Turbulent intensity in the time of 1 s

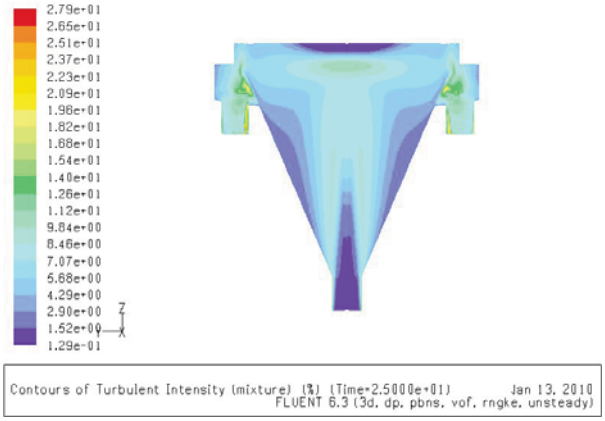


Fig. 11 Turbulent intensity in the time of 25 s

to the fact that water is at present time the coolant in the cooling circuit of the engine.

Figs. 10 and 11 illustrate that the maximal values of turbulence intensity are situated in the area of cylindrical walls of the inflow and outflow pipes, edge of the evaporator cone and at the lithium bromide liquid level in the centre of the evaporator [5].

4. Conclusion

The simulation shows that the cooling medium starts to pour through the edge of the evaporator cone in the time of about 0.96 s after the simulation starts. The inflow and outflow pipes, edge of the evaporator cone and the area of the coolant level in the evaporator centre are the places of the turbulent intensity maximal values.

Acknowledgement:

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Martin Hric – Michal Chmulík – Roman Jarina *

COMPARISON OF SELECTED CLASSIFICATION METHODS IN AUTOMATIC SPEAKER IDENTIFICATION

This paper presents performance comparison of three different classifiers applied in Automatic SpeakeR Identification: Gaussian Mixture Model (GMM), k Nearest Neighbor algorithm (kNN) and Support Vector Machines (SVM). Each classifier represents different approach to the classification procedure. Mel Frequency Cepstral Coefficients (MFCC) were used as feature vectors in the experiment. Classification precision for each classifier was evaluated on frame and recording level. Experiments were conducted over dataset MobilDat-SK, which was recorded in mobile telecommunication network. Experiment shows promising results for SVM classifier.

Keywords: *kNN, SVM, GMM, MFCC, speaker identification.*

1. Introduction

Nowadays, speaker recognition is one of the basic tasks in various systems for Automatic SpeakeR Identification (ASRI), audio documents retrieval, forensic analysis, etc. Such systems allow recognizing "who is talking" from the speech signal. Identification system consists of various parts working together. In this paper, we deal with three different classification approaches for ASRI system, namely Gaussian Mixture Model (GMM), k Nearest Neighbor (kNN) and Support Vector Machines (SVM). Precision of the classifiers is experimentally evaluated by tests performed on the same dataset. We also focus on ability of the selected classifiers to be trained from limited amount of speech data. Such property is crucial in applications as speaker segmentation and matching in audio stream, or speaker retrieval in digital audio archives using Query-by-Example approach.

The paper is organized as follows. In section 2 each of used classification method is briefly discussed. Section 3 presents results of classification as well as database description, data preparation and parameters of given classifiers.

2. Classification techniques description

In this section, we present three different classification methods. Subsections give a short overview of GMM, kNN and SVM classifiers. The GMM is a typical classification method, which has been successfully used in many applications related to the speech. The SVM method becomes very popular in the present time due to its great classification abilities although it is computational very expensive method. Unlike the model based classification methods as GMM and SVM, kNN represents instance based approach to the classification process. From the set of other available classification methods, the HMM or decision trees can be mentioned.

2.1. GMM classification

In GMM classification, Gaussian mixture model is used for statistical representation of speaker pattern. The distribution of feature vectors, extracted from a speech signal, is modeled by a mixture of Gaussian density functions (Fig.1). For a *D*-dimensional feature vector x, the mixture density for speaker λ_r is defined as [1]:

$$p(x|\lambda_r) = \sum_{i=1}^{M} p_i^r b_i^r(x), \tag{1}$$

where M denotes number of components and p_i^r are mixture weights. Density is weighted linear combination of M component uni-modal Gaussian densities $b_i^r(x)$:

$$b_i^r(x) = \frac{1}{(2\pi)^{D/2}\left|\sum_i^r\right|^{1/2}} \exp\left\{-\frac{1}{2}(x-\mu_i^r)\left(\sum_i^r\right)^{-1}(x-\mu_i^r)\right\}, \tag{2}$$

each one parameterized by mean vector μ_i^r and covariance matrix Σ_i^r. Mixture weights must satisfy the following constraint:

$$\sum_{i=1}^{M} p_i^r = 1\,. \tag{3}$$

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Complete GMM is defined by mean vector, covariance matrix and mixture weights (4).

$$\lambda = \left\{ p_i^r, \mu_i^r, \sum_i^r \right\} \tag{4}$$

Every speaker, who should be recognized, has his own model that is used as his representation instead of utterances in identification procedure.

In computation of covariance matrix, we utilized diagonal covariance matrix, which usually gives better results in recognition compared to full covariance matrix. The best results in parameter estimation were achieved by using the iterative Expectation Maximization (EM) algorithm [1], [2]. In this work, we used 100 iteration steps for estimation of the model.

The identification assignment is maximum likelihood classifier. Main task of the system is to make a decision if input utterance belongs to one of the set of speakers, which are represented by its models λ_1, ..., λ_r, index r denotes number of speakers. This decision is based on computation of maximum posterior probability for input feature vector [1]. NETLAB [13] implementation of GMM classifier is applied in the experimental part.

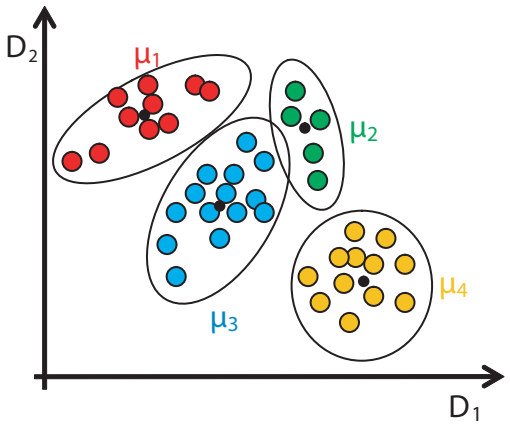

Fig. 1 Example of modeling 2-dimensional data using 4-Gaussian mixtures

2.2. kNN classification

The kNN algorithm (k Nearest Neighbor) can be classed as a nonlinear nonparametric classification method [3]. This algorithm is based on a very simple principle that similar data are close to each other in the searching or data space. In other words, the kNN finds for every object from test data set of k objects in the training data that are closest to the test object (nearest neighbors). The label assignment is usually based on the rule of majority voting, e.g. the most frequent class from the k nearest neighbors for given test object determines the class where this object should belong. A value of k dictates a number of closest objects from training data that are taken into account at the label assignment. If the value is too small, then the result can be sensitive to noise points (objects). If it is too large, then the neighborhood may include too many points from other classes.

Example of k-value impact to classification result is depicted in Fig. 2, where kNN algorithm classifies two dimensional data into two classes. First circle represents region with three neighbors taking into account at decision, where the orange point belongs ($k = 3$). In this example, the classified point belongs to the "red" class. But in the case that six neighbors are considered ($k = 6$) at label assignment, classification result is opposite and unknown point belongs to the "blue" class.

Besides a k-value, the distance metric is important to the kNN algorithm. As can be clearly seen, the distance metric represents the measure of data similarity. The choice of particular distance metric usually depends on the given classification problem. Euclidian (5) or Mahalanobis (6) distance measure are commonly used [3] and the distance between training data vector z and testing vector x are defined as follows:

$$d(x,z) = \sqrt{\sum_{k=1}^{n}(x_k - z_k)^2}\,, \tag{5}$$

$$d(x,z) = \sqrt{\sum_{k=1}^{n}(x_k - z_k)\cdot R^{-1}\cdot(x_k - z_k)'}\,, \tag{6}$$

where n is number of attributes (dimension) and R is the covariance matrix.

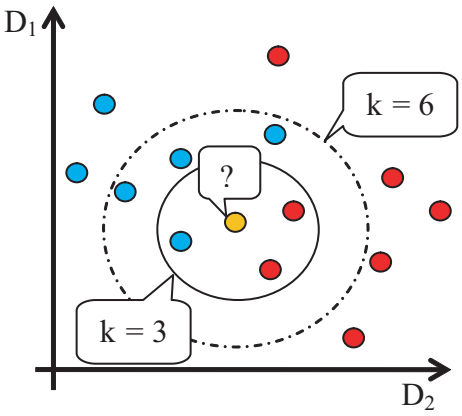

Fig. 2 Example of kNN classification

Regardless the simplicity of kNN, this method is well suitable for multi-modal classes, very flexible and belongs to top 10 data mining algorithms (IEEE Conference on data mining 2007 [3]).

2.3. SVM classification

SVM is a learning procedure based on Vapnik's statistical learning theory [4] proposed in 1979. Classification task includes

a separation of data into two sets – first set consists of data for training process and the second one for testing procedure.

Training set instance-label pairs (x_i, y_i), $i = 1, 2, ..., l$ where $x_i \in R_n$ and $y \in \{1, -1\}$l, the SVM requires the solution of the following optimization problem defined as [5]:

$$\min_{w,b,\xi} \quad \frac{1}{2} w^T w + c \sum_{i=1}^{l} \xi_i , \tag{7}$$

subject to:

$$y_i \left(w^T \varphi(x_i) + b \right) \geq 1 - \xi_i , \xi_i \geq 0 . \tag{8}$$

Each instance in the training set contains features of observed data and class label identifying particular class – in our task it is the index of speaker. The term specified in the following equation

$$K(x_i, x_j) \equiv \varphi(x_i)^T \varphi(x_j) , \tag{9}$$

denotes the kernel function. Training vectors are mapped into higher dimensional feature space by the kernel function. Example of using the kernel function is depicted in Fig. 3. Data from two dimensional feature space are mapped into higher three dimensional feature space by kernel function. There are four basic kernel functions – linear, polynomial, radial basis function (RBF) and sigmoid. RBF kernel function, which was used in our experiment, is defined [4]:

$$K(x_i, x_j) = \exp\left(-\gamma \left\| x_i - x_j \right\|^2 \right) , \tag{10}$$

where $\gamma > 0$.

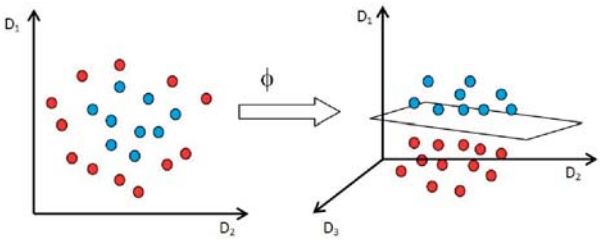

Fig. 3 Example of features mapping using kernel function

Aim of the SVM is to find a linear separating hyperplane with the maximal margin in this higher dimensional space. C is the penalty parameter of the error term. Value of penalty parameter must suffer condition $C > 0$. Not every function can be used as kernel, only those that comply with Mercer's conditions [6].

For SVM classification system, every attribute of the data is scaled to range $[1, -1]$. The main advantage of scaling is to avoid attributes in greater numeric ranges dominating those in smaller numeric range [5].

SVM classifier requires setting up one or more parameters. In our experiment, we applied C-SVM formulation: included in implementation LIBSVM [7] with RBF kernel function; therefore we searched for two model parameters C and γ. We used Particle Swarm Optimization (PSO) [8] technique for parameter selection task.

3. Experimental results

Selection of classifier and feature vectors are one of the crucial parts of each classification system. Classification task is to correctly identify speakers known to the system based on the previous learning procedure. This learning process could be done by various techniques based on statistical modeling, distance measure or non-probabilistic linear binary classifier. Feature extraction is the process, when feature vectors are extracted from speaker utterances that represent information of identity to system better than the speech signal itself. Fig. 4 depicts a block diagram of classification system that we used in the experiments.

In evaluation process, we used MobilDat-SK database [9], [10]. The MobilDat-SK is corpus of mobile telephone speech recorded over GSM telecommunication network in Slovak language. From the corpus consisting of 1100 speakers, utterances of 20 speakers were randomly selected, while 3 different utterances pronounced by the same speaker were stored for each of the 20 speakers. We decided to use only 20 speakers for each test because of high computational expenses and thus long training procedure of SVM classifier. In many real applications (e.g. speaker separation and indexing in audio documents), this amount of speakers is usually sufficient. In the experimental part, we were also investigated classification ability of particular classification method when only a few training data is available. Each utterance has duration of approx. 8 seconds and is stored as uncompressed PCM WAV file with 16 bits resolution, and 8 kHz sample frequency. From the speaker utterances, 22 MFC coefficients were extracted as the speech features. Since MFC coefficients have great ability to describe a speech signal, we decided to employ these audio features. The frames of 30 ms length and 10 ms overlap were used. Silent frames for each speaker utterances were dropped out using short time energy threshold and simple GMM-based voice activity detector. We used 2 utterances (approx. 16 seconds) as a training data and 1 utterance as a test data for every speaker.

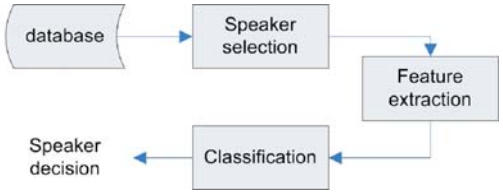

Fig. 4 Classification system

We applied two different approaches during performance evaluation of proposed classifiers. First, we compared classification accuracy on frame level, were each feature vector influences of the overall performance. The second approach of evaluation was per-

formed over whole recordings or utterances and the most frequently class occurred in the utterance were assumed as the class where the classified utterance belongs to. As a classification accuracy measure, F measure based on precision and recall was applied. For every classifier, each test was run 30 times to obtain the statistical credibility of classified data and the final values were averaged. All the tests were run in MATLAB program environment.

We used 3 different classifiers with the following parameters:

- GMM with probability density function (PDF) composed of 8 Gaussians and diagonal covariance matrix. The number of Gaussian components was chosen according to previous studies of training GMM on small amount of data [11], [12].
- SVM with RBF kernel function – model parameters selection were performed over parameters range $C = \{2^{-5}, 2^{-4.9}, ..., 2^{19.9}, 2^{20}\}$ and $\gamma = \{2^{-20}, 2^{-19.9}, ..., 2^{4.9}, 2^{5}\}$, criterion function for model parameters selection was 5-fold cross validation accuracy,
- kNN with $k = 7$ neighbors and Euclidean metric.

Experiment results for classifiers are shown in Tab. 1, Fig. 4.

Classification accuracy results Tab. 1.

Method	GMM	kNN	SVM
Frame level accuracy [%]	16.58	43.21	49.90
Record level accuracy [%]	31.89	92.15	98.11

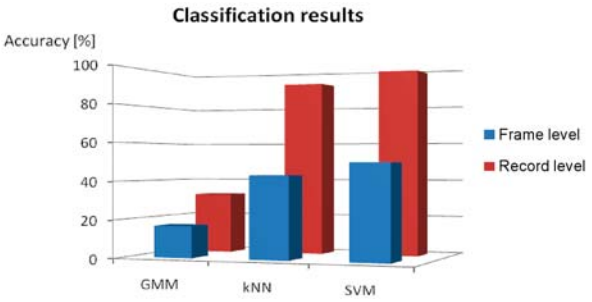

Fig. 4 Classification accuracy results

4. Discussion of the Results and Conclusion

In this paper, we described and evaluated three different classifiers used for speaker identification task. Classification accuracy for the dataset MobilDat-SK was computed for frames as well as for whole recording of each speaker consisting of all frames. The best classification accuracy of 98.11 % was achieved by SVM classifier. Thus the great discrimination properties of SVM as well as its ability to be trained on few examples have been proven by our experiments. Despite of high classification accuracy the disadvantage of SVM are the extremely high computational requirements resulting to very slow training procedure. It is interesting that the KNN classifier scored comparable classification accuracy – 92.15 % despite of its simplicity. The drawback of kNN is increasing computational complexity with large database. GMM classifier achieved significantly worse classification accuracy – 31.89% – than the other two classifiers. Reason of this fact is lack of training data for GMM classifier (Note, less than 16 seconds of speech data were utilized for training of the classifier).

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Miroslava Mrvova – Peter Pocta *

QUALITY OF SYNTHESIZED SPEECH: IMPACT OF THE NEWEST CODING APPROACHES

This contribution deals with the issue of quality of synthesized speech. It introduces principles and approaches of creating this type of speech and basic methods and techniques used to assess the quality of synthesized speech. This article also offers a short overview of relevant experimental studies discussing issues related to this kind of speech and its quality assessment. Finally, it investigates effect of the newest coding approaches (e.g. Speex, iLBC, EVRC-B, etc.) on quality of naturally-produced speech and synthesized speech (generated by diphone and unit-selection synthesizers) predicted by two different objective models and provided by subjective tests.

Keywords: *synthesized speech, synthesizer, text-to-speech systems, quality assessment, coding approaches, degradation.*

1. Introduction

In recent years, synthesized speech achieves massive increase of interest in the case of development and utilization. The reason might be the fact that speech is the most natural human form of communication and therefore there are efforts to imitate human voices. Systems used for speech synthesis offer wide range of utilization, because of their level of maturity, which allows them to be integrated for example in a place where other way of communication can not be used or in the human computer interaction systems involving higher number of modalities. Therefore the synthesized speech is implemented in many applications of daily life where this kind of speech replaces real human speaker. The synthesized speech is mainly deployed, for example, in systems providing reports containing frequently changing and routine information (weather forecast, timetable), in systems offering different dialogue situations (games) or reading various scripts (SMS-reader, e-mail reader).

In contrast to naturally-produced speech, synthesized speech represents artificially made speech, i.e. given text utterance spoken by computer. It is created by unifying pieces of speech, recorded by speaker and stored in speech database. These systems are also termed as speech synthesizers. They are based on transformation technology called text-to-speech systems (TTS). In order to realize this transformation, TTS consists of many algorithms and modules. Fig. 1 shows schematic representation of text-to-speech system.

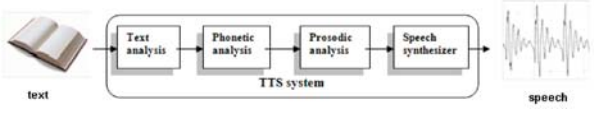

Fig. 1 Schematic representation of text-to-speech system (TTS)

In principle, functions of the TTS system can be divided into the following parts:

- Text analysis (normalization) – performs analysis of the text, which is separated into sentences. Numbers, abbreviations, symbols are replaced by their own word transcription,
- Phonetic analysis – transforms the text to voice (phonemes),
- Prosodic analysis – applies prosodic language characteristics to the selected phonemes, such as melody, speaking rate, volume, emphasis, pauses, accent, etc.
- Synthesis of the speech – generates speech signal from given sequence of prosodically-modified phonemes.

Nowadays, there are three different approaches available to create this type of speech. The currently most widely used of them is concatenate synthesis, which is restricted to speech signal and based on combining short speech strings to form a longer one. Output of this synthesis is the most naturally sounding synthesized speech. There are three main types of concatenate synthesis: unit-selection synthesis, which uses large database of recorded pieces of speech, such as words, phrases, sentences, etc. This synthesis produces voices, which are mostly indistinguishable from naturally-produced ones. Second type is diphone synthesis. The database used for this purpose consists of all diphones found in particular language. In contrast to former approach (unit-selection synthesis), overall quality of diphone synthesis is generally worse. Finally, last approach is domain-specific synthesis; its database consists of pre-recorded words and phrases, which makes it restricted to certain scripts.

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Other approach is formant synthesis (widely deployed in past), which is based on the fundamental frequencies of amplitude spectrum of voice (formants). Systems deploying this synthesis generate artificial, robotic sounding speech (with constant quality), which cannot be confused with naturally-produced speech. Lastly, articulation synthesis represents new approach, which deals with straight human vocal track imitation, i. e. overall speech generation process. Synthesis is focused on providing isolated sounds, phones, simple words, etc. This approach has been poorly investigated at the cost of its complexity.

Definitively, synthesized speech should be indistinguishable from the human actual speech. It should characterize the most reliable copy not only in case of quality as well as in speaking style. There are efforts to ensure that synthesized speech will be the most natural, not fatiguing, not monotonous, and does not make efforts with respect to listening or comprehension [1].

For determining the output subjective quality of TTS systems (voice output devices), an application-oriented listening-only test ITU-T Recommendation P.85 [2] is recommended to be used. In general, ITU-T Recommendation P.85 is based on opinions of group of test subjects (at least 24 people), who listen to given synthesized samples and fill out the questionnaires. This recommendation defines the following rating scales: overall impression, acceptance, listening effort, comprehension problems, articulation, pronunciation, speaking rate and voice pleasantness. Assessment is based on rating called MOS (Mean Opinion Score), which represents the average values representing opinions of testing subjects or efforts needed to listen to synthesized speech expressed on the 5-point quality scale varied from bad (1) to excellent quality (5). The speaking rate uses 5-point scale varied from too slow (1) to too fast (5) and the acceptance uses only 2-point scale (yes – no). Each sample is played twice to each test subject. In first phase subjects answer questions on the information found in samples (e.g. train number, price the item). In second phase subjects are asked to assess the speech quality using one or more rating scales. For assessing the quality, two types of questionnaires, namely type I (Intelligibility) and Q (Quality) are used. Although, this method has been criticized for its shortcomings [3], [5], [25]; it is still frequently used for overall assessment of the speech output of TTS systems; but when such output is impaired by transmission degradations, a slightly modified version of this method or classical test according to ITU-T Recommendation P.800 [4] are mainly deployed.

In general, the quality of synthesized speech is evaluated in terms of intelligibility (how well the listener understands given samples) and naturalness (overall speech quality assessment). SUS (Semantically Unpredictable Sentences) belongs to the group of famous intelligibility tests. The semantically nonsense sentences with correct syntax are presented to subjects and their task is to correct the presented sentences. Each utterance is played only once. The most widespread naturalness test is MOS see details above (ITU-T Rec. P.85). Other example of naturalness test is Paired Comparison test (PC), where each sample is presented to subjects in two variants. Listener task is to choose one, which he prefers. Common to all these methods is that they are based on listener's judgments, which makes them inappropriate in terms of time and finance. Authors in [5], [6], [7] investigated the performance of the methods used for subjective assessment of quality of synthesized speech, especially the accuracy and reliability of approach defined in ITU-T Rec. P.85. In [5], the approach presented in ITU-T Rec. P.85 was compared with other available methods (test of intelligibility (SUS) and test of naturalness (MOS)) for evaluation of text-to-speech systems. Their aim was to investigate whether this approach provides the better performance than SUS and MOS test. Results showed that SUS test provides more rigorous measure of which systems were more intelligible than the other tests. However, the SUS revealed more errors which could be grouped. Overall, the ITU test is more suitable for testing intelligibility of specific application than a general purpose test. In particular, the reliability of this standard for evaluation of text-to-speech systems was investigated in [6]. Authors examined how the ranking of TTS is changing across different text genres and listening sessions. Outputs were compared with pair-comparison test (PC), using above mentioned aspects. In terms of reliability, both tests (P.85, PC) showed very similar results (from absolute score and ranking perspective). In terms of selectivity, there were minor differences between the systems across genres. In [7], the authors have compared naturally-produced speech and synthesized speech with respect to type of the speaker (male, female). Overall, female human voice was rated more persuasive and livelier than synthetized voice. Moreover, synthesized speech spoken by female speakers was rated worse in contrast to male synthesized voice. Finally, they have observed gender stereotyping effects where the results revealed that female listeners assessed male voices more favorably than vice-versa.

In order to make evaluating the perceived quality of synthesized speech more effective is necessary to have instrumental tools. Such tools should be able to predict the quality as it would be judged in an auditory tests by test subjects. At this moment, there are not available standardized models (tools) for objective quality assessment of synthesized speech. However, there are ongoing research efforts dealing with this issue, e.g. works presented in [8–10]. In order to design a new instrumental quality measure for text-to-speech systems (for both male and female synthesized speech), authors try to combine different approaches. In [8] model is based on hidden Markov models (HMM) trained on naturally-produced speech. In [9], HMM-based comparison of features extracted from synthesized signal with parametric description of the synthesized speech signal (parameters from ITU-T Rec. P.563 and parameters related to vocal expression patterns) is used in this approach. In [10], the approach presented in [9] was evaluated on auditory test databases from the Blizzard Challenges 2008 and 2009.

Oppositely, there are also ongoing efforts to verify whether the existing models designed to assess the quality of naturally-produced speech, like PESQ (Perceptual Evaluation of Speech Quality) [11–13], P.563 [14], [15], ANIQUE+ (Auditory Non-Intrusive Quality Estimation Plus) [16], [17], are capable to predict the quality of synthesized speech to a certain degree [18–20], [24], [25]. In order to realize this, many experiments were performed.

For instance, in [18], intrusive model PESQ was applied to assess the quality of synthesized speech. Authors concluded that PESQ model can be used for evaluation of synthetized speech without usage of subjective tests. On the other hand, PESQ can not be deployed for small size of diphone samples. The behavior of nonintrusive model P.563 in case of assessment of synthesized speech is investigated in [8], [19–22], [25]. Based on the results presented in [19], P.563 is better for predicting impact of transmission channel on quality of naturally-produced voice, however it has lower accuracy in prediction of the overall voice quality. Furthermore, P.563 achieves low correlation with subjective quality ratings for synthesized speech (especially in case of female synthesized voices [22]). In [20], the authors provide an explanation for this low correlation which can result from the proposed optimization of feature combinations and mapping functions in order to improve a performance of P.563 model for predicting the quality of synthesized speech. In [21] the performance of the original and modified P.563 model was also tested on synthesized speech data obtained in Blizzard Challenges 2007 and 2008. Experimental results have revealed that the algorithm, using the proposed modifications attains noticeable improvements in comparison to the original one.

Finally, there are also available studies dealing with the impact of various speech quality impairments (like noisy-type degradations, low bit rate codecs, etc.). In [23], Sebastian Moeller focused on the following issue: whether the impact of the transmission channel on the quality of synthesized speech is different from the impact on naturally-produced speech. The investigation was focused on e.g. noisy-type degradations which affected the quality of both synthesized and naturally-produced speech in the same amount; and on low bit rate codecs, which had a bit different impact on the quality of both kinds of speeches. Noisy codecs (e.g. G.726, G.728) cause more significant impact on the overall quality of synthesized speech than the artificially sounding codecs (e.g. G.729, IS-54). The signal-based comparative models, such as PESQ, TOSQA (Telecommunication Objective Speech Quality Assessment) have been applied for prediction of the quality of synthesized and naturally-produced speech impaired by low bit rate codecs. Variances in results between this models and auditory test are more considerable for synthesized than naturally-produced speech. Basically, PESQ and TOSQA are also capable to predict the quality of transmitted synthesized speech to certain degree. PESQ provides a good approximation of the quality degradation to be expected from circuit noise, whereas TOSQA model underestimates the quality at high noisy levels [24]. In [25], the authors also compared the results from various auditory tests with the predictions provided by three single-ended models (P.563, Psytechnics, ANIQUE+) using naturally-produced and synthesized voices. The samples used in this study were transmitted through different telephone channels (same impairments as used in study published in [23]). Test realized in [25] revealed that these models provide distinct correlation with results of auditory tests in the case of particular experiments.

The rest of the paper is organized as follows: Section 2 describes the investigation of impact of the newest coding approaches on speech quality in case of naturally-produced and synthesized speech usage (experimental description). In Section 3, the experimental results are presented and discussed. Finally, Section 4 concludes this paper.

2. Description of experiment

The signals transmitted through modern telephone networks are impacted by amount of degradations. Traditional, connection-based networks (analogue or digital) are affected by noise, loss, frequency distortion. Non-linear distortions from low bit-rate coding-decoding processes, talker echoes resulting from the delay, overall delay due to signal processing equipment, or time-variant degradations linked to packet or frames loss are examples of transmission degradations for new types of networks (mobiles or IP-based ones). A combination of all these impairments will be encountered when different networks are interconnected to form a transmission path from the service provider to the user. Thus, the whole path has to be taken into account for determining the overall quality of the service operated over the transmission network. As mentioned above, one of the new impairments introduced by mobile or IP-based networks is non-linear distortion from low bit-rate coding-decoding processes. Currently, this degradation is poorly investigated, especially with respect to its influence on synthesized speech [23]. This fact motivated us to investigate the impact of this distortion on speech quality. In particular, here we focus on an impact of newest coding approaches (e.g. Speex, iLBC, EVRC-B, etc.) on speech quality predictions provided by PESQ and P.563 in case of naturally-produced and synthesized speech usage.

2.1. Reference signals and experimental scenario

In this experiment, three sentences in Slovak language with length of 12 seconds were used as reference signals. Two synthesized speech signals generated with two different TTS systems (male voices) and one naturally-produced signal (recorded in an anechoic environment; with non professional male speaker) are under consideration. The decision about using male voice came from the previous study published in [7]. The tests have proved that the message produced by the male synthetic voice was rated as more favorable (e.g. good and more positive) and was more persuasive, in terms of the persuasive appeal, than the female synthetic voice. These particular differences are perceptual in nature, and more likely due to differences in synthesis quality between male and female voices.

TTS system 1 was diphone synthesizer and TTS system 2 was unit-selection synthesizer. Both systems have been developed at the Institute of Informatics of the Slovak Academy of Sciences. More about those synthesizers can be found in [26].

All speech samples have been normalized to an active speech level of −26 dB below the overload point of the digital system, when measured in accordance to ITU-T Recommendation P.56 and stored in 16-bit, 8000 Hz linear PCM; background noise was not present.

The reference signal described above were processed by following codecs ITU-T G.729AB [27] (bit rate: 8 kbps, frame size: 20 ms), ITU-T G.711 [28] (bit rate: 64 kbps, frame size: 0.125 ms), GSM-FR (GSM 06.10) [29] (13 kbps, 20ms), Internet Low Bit Rate Codec (iLBC) [30] (15.2 kbps, 20 ms), Speex [31] (4–8 kbps, 20 ms) and Enhanced Variable Rate Codec version B (EVRC-B) [32] (9.6 kbps, 20 ms). In principle the codecs used in this study can be divided into two groups. First group characterizes artificially (unnaturally) sounding codecs, such as ITU-T G.729AB, Speex, iLBC, GSM-FR and EVRC-B, whereas the ITU-T G.711 codec represents second group called naturally sounding codecs.

Speech quality was assessed by intrusive model PESQ [11-13] and nonintrusive model P.563 [14], [15]. In case of PESQ model, the raw PESQ scores were then converted to MOS-Listening Quality Objective narrow-band (MOS-LQOn) values by this equation [33]:

$$y = 0.999 + \frac{4.999 - 0.999}{1 + e^{-1.4945*x + 4.6607}} \quad (1)$$

where x represents the obtained PESQ scores and y the computed MOS-LQOn score.

Moreover, the accuracy of PESQ's and P.563's predictions was assessed by comparing the results with subjective quality assessment.

2.2. Subjective quality assessment

As mentioned above, the obtained predictions provided by PESQ and P.563 models were compared with subjective assessments to assess their accuracy. The subjective listening tests were performed in accordance to ITU-T Recommendation P.800 [4]. Always up to 9 listeners were seated in listening chamber with reverberation time less than 190 ms and background noise well below 20 dB SPL (A). All together, 25 listeners (11 male, 14 female, age range 21-30 years, mean 24.08 years) participated in the tests. 18 of them reported to have no experience with synthesized speech. The subjects were paid for their service.

The samples were played out using high quality studio equipment in random order. Results in Opinion Score 1 to 5 were averaged to obtain MOS-Listening Quality Subjective narrowband (MOS-LQSn) values for each sample. All together, 18 speech samples were used for subjective testing of coding impact.

3. Experimental results

In this section, we present and discuss the results coming from this investigation. As mentioned above, this study focuses on a comparison of the predictions provided by objective models PESQ and P.563 with subjective scores using naturally-produced and synthesized speech, whereas different current codecs have been applied (ITU-T G.711, ITU-T G.729AB, GSM-FR, Speex, iLBC and EVRC-B) to degrade the quality of the reference signal.

Figure 2 depicts behavior of the investigated codecs on quality prediction provided by two objective models (PESQ, P.563) and by auditory tests for naturally-produced speech. We can see that artificially sounding codecs are rated significantly worse in both models' predictions compared to the auditory test. Whereas for the ITU-T G.711 codec (naturally sounding codec) the predicted quality especially provided by PESQ is in better agreement with the auditory results, as in previous case. Furthermore, P.563 model under-predicts the quality much more than PESQ in all cases.

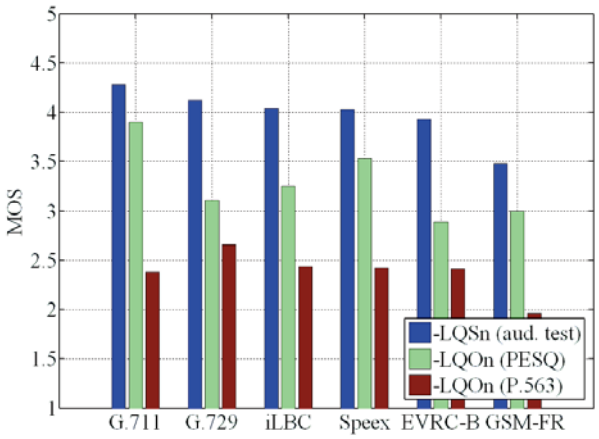

Fig. 2 Impact of the investigated codecs on MOS-LQSn and MOS-LQOn's predicted by PESQ and by P.563 in case of naturally-produced speech

Figs. 3 and 4 show the results obtained for diphone synthesizer and unit-selection synthesizer, respectively. As can be seen from Fig. 3, diphone voice (sounds less natural than unit and natural voices) was particularly disliked by test subjects. This is probably the reason for such small ratings provided by subjects. On the basis of the presented fact, we decided to omit the diphone voice from the further analysis of the behavior of synthesized speech under coding impairments. On the other hand, the behavior of the diphone voice can be used as an example how higher unnaturalness of the signal can affect the opinions of the test users. Fig. 4 depicts the effect of the investigated codecs on MOS-LQSn and MOS-LQOn predicted by PESQ as well as P.563 models for unit voice. In contrast to naturally-produced speech (see Fig. 2), the predictions of both models are in good agreement – with the exception of some predictions provided by P.563 model, like for ITU-T G.711 codec, etc. – with the auditory ratings.

Moreover, Figure 5 presents a comparison of the behavior of the synthesized speech with the behavior of naturally-produced speech from auditory ratings perspective. As can be seen from Figure 5, there are some differences between subject ratings for the synthesized speech generated by unit-selection synthesizer and naturally-produced speech. The observed differences may be due to differences in quality dimensions perceived as degradations by the test subjects. Whereas the 'artificiality' dimension introduced by the investigated 'unnatural sounding' codecs is additional degradation

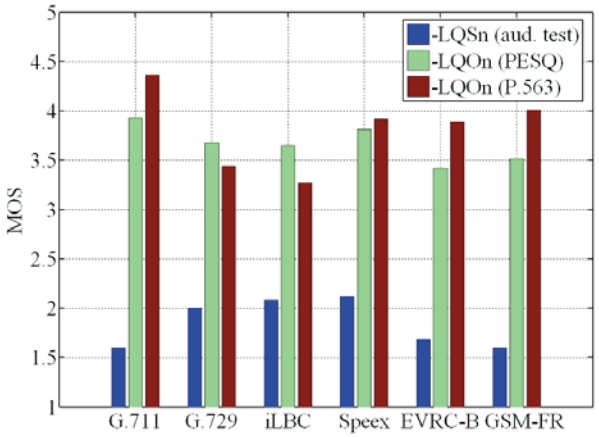

Fig. 3 Impact of the investigated codecs on MOS-LQSn and MOS-LQOn's predicted by PESQ and by P.563 in case of synthesized speech generated by diphone synthesizer

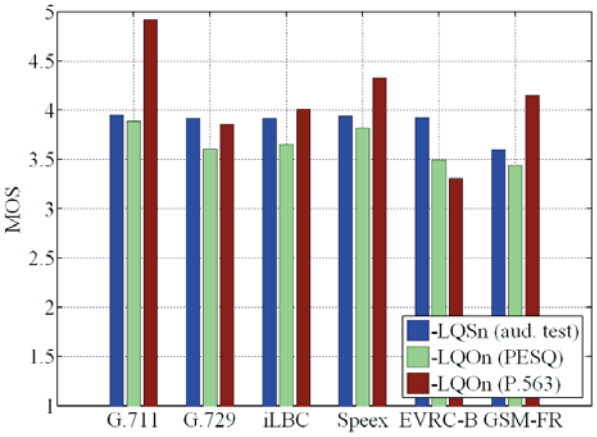

Fig. 4 Impact of the investigated codecs on MOS-LQSn and MOS-LQOn's predicted by PESQ and by P.563 in case of synthesized speech generated by Unit-selection synthesizer

for the naturally-produced speech, this is not a case for the synthesized speech, which already carries a certain degree of artificiality.

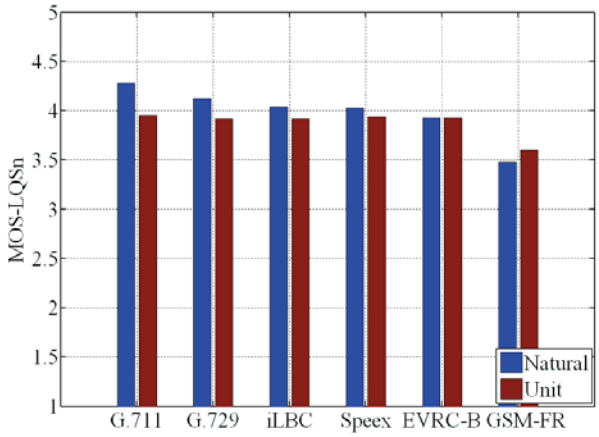

Fig. 5 Comparison between the subjective ratings for naturally-produced speech and the ratings for synthesized speech generated by unit-selection synthesizer

The results presented here are well in line with the results described in [24]. The synthesized speech is assessed a little more pessimistically than natural speech for ITU-T G.729 codec, which is shown in Figure 5.12 (p.225, [24]). On the other hand, the synthesized speech is rated a bit more optimistically by subjects than naturally-produced speech for IS-54 codec and its combinations. The effect is much more dominant for its combinations. Unfortunately, we did not investigate this codec as well as its combinations in this study but then the GSM-FR codec was involved in this study which belongs to similar family of codecs. The same behavior as for IS-54 in [24] was also reported here for GSM-FR, probably because of very similar special techniques deployed in both codec-families. Regarding the predictions of PESQ (see Figures 5.15-5.16 [24]), which were also investigated in the discussed study, they are more or less in line with our results, particularly for ITU-T G.729 codec (see Figures 2 and 4). Unfortunately, the study published in [24] is mainly focused on the different types of codecs and its combinations. This study can serve as an extension of the study published in [24].

4. Conclusion

The paper provided a brief overview of assessment of quality of synthesized speech. In addition, a overview of the current state-of-the-art of research dealing with this issue has also been described here, summarizing the experimental studies investigating the performance, accuracy and reliability of existing approaches and models (mainly designed for evaluating the quality of naturally-produced speech, but also new models designed directly for assessing the quality of synthesized speech) to evaluate the quality of synthesized speech. Finally, the paper described the experiment dealing with the impact of current codecs (ITU-T G.729AB, Speex, iLBC, GSM-FR and EVRC-B, ITU-T G.711) on the quality predicted by two objective models (intrusive PESQ, nonintrusive P.563) using naturally-produced and synthesized voices as an input signals. The obtained predictions provided by both models were compared with the ratings coming from the auditory test. The experiment revealed that the investigated codecs have a different impact on the quality of both naturally-produced and synthesized speech. Comparing the performance of both objective models, PESQ algorithm seems to be more appropriate for assessing the quality affected by the newest coding approaches than P.563 algorithm, especially in case of naturally produced speech.

Future work will focus on the following issues. Firstly, we would like to investigate the performance of a brand new ITU-T intrusive model for predicting speech quality, namely POLQA under the same conditions as investigated here (as a part of the characterization phase of this model). Secondly, on the basis of the results

obtained for the P.563 model, we have decided to try to design a new non-intrusive model for such conditions (synthesized speech and IP impairments). Thirdly, we are planning to extend the E-model towards the synthesized speech impaired by the time-varying and coding impairments.

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Michaela Vojsovicova – Tatiana Liptakova – Viera Zatkalikova *

RHEOLOGICAL CHARACTERISTICS OF THERMOPLASTIC POLYMERS AFTER DEGRADATION

Selected rheological properties of thermoplastic polymer materials before and after exposure in different environments were evaluated by Frequency sweep test, which monitors changes in viscoelastic properties of polymers with respect to their molecular structure and their behavior in thermoplastic processes. Samples of tested material were subjected in UV radiation, moist soil with higher concentration of chlorides and solution of n-hexane for exact period. Degradation process resulted in changes of complex dynamic viscosity, storage and loss modulus, changes in molar mass and its distribution.

1. Introduction

In the last few decades, polymers have been widely used materials in industry and their utilization in engineering applications is widely growing all over the world. Their versatility makes them suitable for a whole range of applications, and comes from the capability of manufacturers to tailor microstructures and properties through control of the processing conditions [1].

Polymer materials represent an important area in which they are becoming predominant against other materials and have increased considerably and rapidly. Their relatively low cost, ease of installation, transportation, and long-term durability against environmental degradation (harmful environmental attack such as corrosion, rust and higher thermal stresses) make plastics an attractive alternative to metals. Among the most common polymers utilized in such applications are polyethylene (PE) and polypropylene (PP) [2].

Rheology and its experiments reveal information about the flow behavior of liquids but also the deformation behavior of solids, because it is the typical behavior of polymers. Changes induced by the environment with degradation effect can be evaluated by rheological measurements which monitor changes in viscoelastic properties of the tested polymers. The fundamental of rheological characteristics is viscosity which defines the internal resistance of material against its creep generated by external forces [3, 4]. It is necessary to realize the dual character of majority of polymer materials from viscoelastic point of view. The action of external force on the ideal viscous material results in its deformation i.e. irreversible locomotion (movement) of macromolecules and after removal of the external force material retains its "new" shape. The action of external force on the ideal elastic material results in its deformation but after the removal of the external force, the material returns to its original shape. Polymers are generally characterized by the viscoelastic nature, which means that external forces cause partly permanent (viscosity element of polymer) and partly reversible (elastic element of polymer) deformation [5, 6].

Viscosity has a high importance for polymer processing, the change of viscosity is determined by changes of particular factors (temperature, pressure, molecular weight and its distribution, structure of the polymer, presence of additives in the polymer), which are characteristic for the polymer and may vary according to the effect of degradation processes [7].

The aim of this study is the comparison of selected rheological properties of thermoplastic polymer materials before and after exposure in different environments with a degradation effect.

2. Experimental material and conditions of preparation

The polymers used in this study are commercially available and provided in the form of pellets by the plastics company Nitra and Licharz company. Polyethylene PE 1400 with the trade name Finathene XS 10 YCF S 70111902, high density, low pressure PE 500 with the trade name PE HMW, and polypropylene PP was used as an experimental material.

These thermoplastics materials pose very good chemical resistance, relatively low density 0.91 – 0.96 g/ cm^3, low absorption, good resistance at high negative temperature, good workability and some other properties like coefficient of friction, abrasion resistance and impact toughness [5].

Polymer samples of plate shape with dimension of 10 × 55 × 3 mm were exposed in different environments with degradation

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effect. Samples of PP and PE 500 were exposed to aliphatic hydrocarbon n-hexane, immersed in a separated container for 3 and 6 months at laboratory temperature. PE 1400 samples were subjected to long-term (485 days) exposure in moist soil with high chloride concentration simulating conditions of the real working environment. Accelerated aging tests of PE 1400 samples were carried out in UV chamber for a period of 139 days, which represents 700 cycles and intake energy of 5264 kJm^{-2}. One cycle in the UV chamber is represented by 4.8 hours of testing with delivered energy of about 7.52 kJm^{-2} per cycle. Daily cycle runs for 3.8 hour (temperature of 62 ± 3°C; relative humidity of 50 ± 5%; intensity of radiation 0.55 Wm^{-2}) and 1 hour night cycle (temperature of 38 ± 3°C; relative humidity of 50 ± 5%; intensity of radiation 0 Wm^{-2}).

3. Measuring technology and interpretation of used method

The evaluation of polymer degradation was performed by measuring of rheological properties by oscillating rheometer Physica Rheometer MCR 301 with the Convection Temperature Device CTD 450, a unique chamber that offers gradient free measurements and a direct measure of the sample temperature. The sample temperature equals the sensor temperature at any time. The chosen method was Frequency Sweep test (FS), which characterizes the viscoelastic properties of polymers with respect to their molecular structure and their behavior in thermoplastic processes [4, 8].

The sample thermoplastic polymer was placed between two parallel plates with diameter of 25 mm at a gap of 1 mm. Measurements were carried out at the temperature of 160 °C and 180 °C, according to the nature of the material and following conditions: an amplitude of $\gamma = 5\%$, an angular frequency of $\omega = 500 - 0.051$/s.

The principle of material evaluation is based on evaluation of measured parameters which are shown in the diagram (Fig. 1). The process of degradation is followed by changes of molecular mass (as networking or macromolecular chains breaking) which should be reflected in the measured parameters.

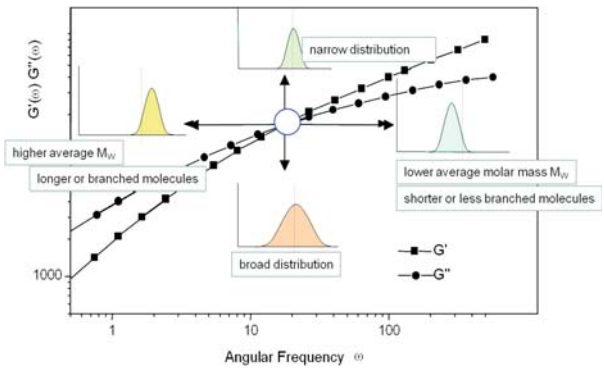
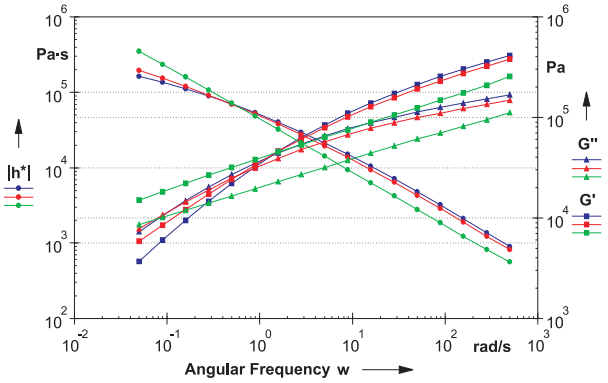


Fig. 1 Determination of selected rheological characteristics G′, G″ of material during FS test

The analysis of the cross-over point (COP) between the storage modulus G' and the loss modulus G'' in the frequency sweep, as seen in Fig. 1, makes it possible to obtain the qualitative picture of the average molar mass and molar mass distribution. Furthermore, we are able to monitor the position of the intersection of the curves characterizing the state of both modulus and indicate the transition from viscous deformation behavior to the more elastic behavior. This COP is qualitative characteristics of the material [9]. The polymer degradation can result in changes of the values of measured characteristics. Shift of the COP in horizontal direction provides information about the average molar mass and shift of the COP in the vertical direction signals the difference in the molar mass distribution.

4. Results and discussion

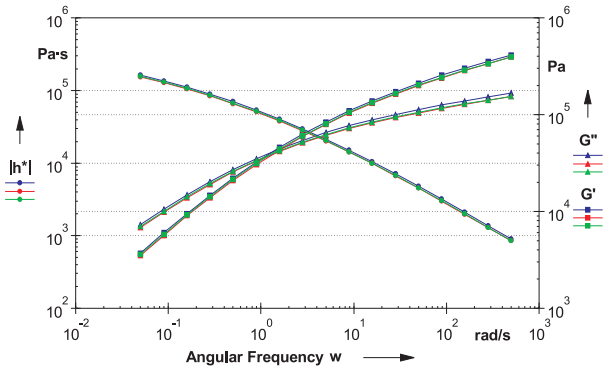
The degradation of PE 1400 after exposure in UV chamber (after 700 cycles) was evaluated by Frequency Sweep test (FS). The differences in viscosity and modulus defining plastic and elastics properties of PE samples are shown in Fig. 2. These measurements were carried out only in exposed surface layers that were replaced from the exposed sample (in depth of 0 to 750 µm and 750 to 1500 µm). There is evident difference in degradation seen from the surface further to the depth and the layer of 750 µm has significantly different viscoelastic properties – material becomes more fragile. Measurement of the sample layer in the depth of 750 - 1500 µm showed that the degradation is much smaller and measured curve is closer to the curve of unaffected sample.



PE 1400 before exposure, PE 1400 in UV (0 - 750 µm), PE 1400 in UV (750 - 1500 µm)

Fig. 2 Rheological properties of PE 1400 after 700 cycles in UV test

Moist soil with higher concentration of chlorides had no significant degradation influence on PE 1400 even after long-term exposure. Fig. 3 shows that polyethylene material was not damaged in surface layers which was verified by measuring replaced layers in particular depth (0 – 750 µm and 750 – 1500 µm) from surface area. According to the results it is clear that neither surface



PE 1400 before exposure, PE 1400 in moist soil (0 – 750 μm), PE 1400 in moist soil (750 – 1500 μm)

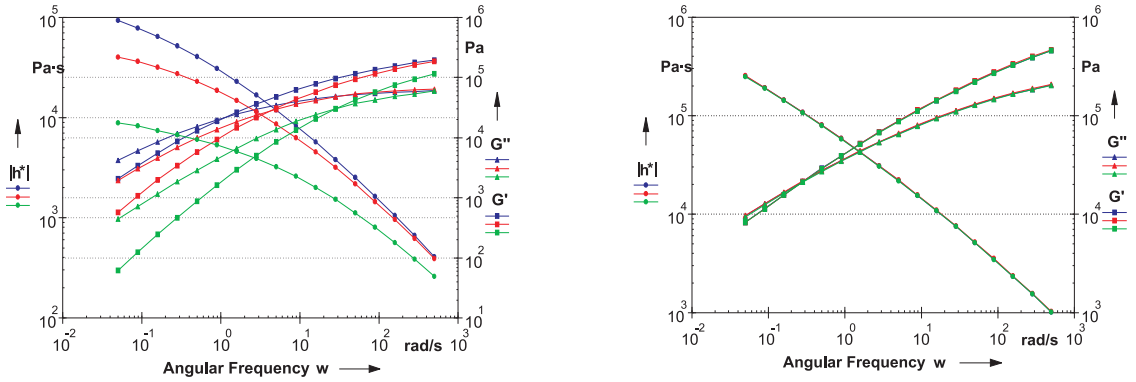
Fig. 3 Rheological properties of PE 1400 after 485 days in moist soil

areas nor subsurface areas were influenced by degradation effect because the values of measured variables indicate almost the same course.

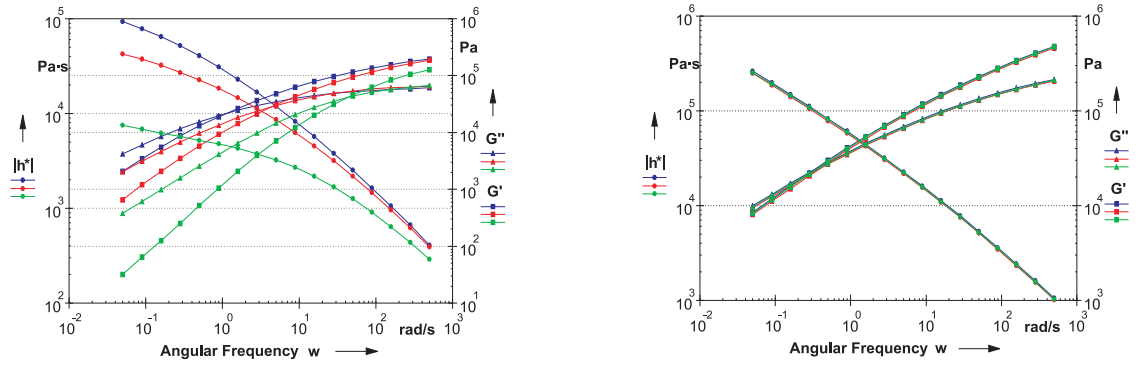
Measurements of PP and PE 500 exposed in n-hexane for period of 3 months (Figs. 4 and 5) and 6 months (Figs. 6 and 7) show the changes of viscosity, as well as G' and G'' modulus in both surface layers but only in PP samples. PE 500 indicates no changes in viscoelastic properties in comparison with the original material. We can monitor that the area in the depth of 300–600 μm is affected more than the surface layer of 0 – 300 μm, in which material properties are much more similar to properties of unexposed material. This phenomenon is not very clear to explain yet and is subjected to further study.

5. Conclusion

- Changes in the structure of studied polymers due to degradation effect in different environment can be sensitively monitored by rheological measurements. This was reflected in the measured rheological parameters and variables like viscosity, molecular mass and its distribution, modulus characterizing elastic and plastic properties.
- The results prove that the exposure of PP and PE 500 in n-hexane only influenced the degradation of PP samples which



PP before exposure, PP 500 exposed in n-hexane (0 – 300 μm), PP 500 exposed in n-hexane (300 – 600 μm)
PE 500 before exposure, PE 500 exposed in n-hexane (0 – 300 μm), PE 500 exposed in n-hexane (300 – 600 μm)
Figs. 4 and 5 Rheological properties of PP and PE 500 exposed in n-hexane for 3 months



PP before exposure, PP in n-hexane (0 – 300 μm), PP in n-hexane (300 – 600 μm)
PE 500 before exposure, PE 500 in n-hexane (0 – 300 μm), PE 500 in n-hexane (300 – 600 μm)
Figs. 6 and 7 Rheological properties of PE and PE 500 exposed in n-hexane for 6 months

varied in particular layers. The rheological characteristics of polyethylene material stay unchanged.
- The long-term exposure of PE 1400 in moist soil had no significant effect on viscoelastic characteristics of tested material.

Acknowledgements

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Radoslav Konar – Milos Mician – Anton Hopko *

ANALYSIS OF BOUNDARY CONDITIONS FOR THE SIMULATION OF WELDING AT THE REPAIR OF GAS PIPELINES WITH STEEL SLEEVE

Theoretical part of the manuscript deals with basic information about repair of gas pipeline with steel repair sleeves and simulation programme SYSWELD. Experimental part includes analysis of boundary conditions in two-pass fillet welding joint. Results of the analysis will be used for simulation in simulation programme SYSWELD.

Keywords: *Steel repair sleeves, L360NB, SYSWELD.*

1. Introduction

The article deals with the issues of repairing defects at steel gas pipes, in particular of permanent repairs with using steel sleeves.

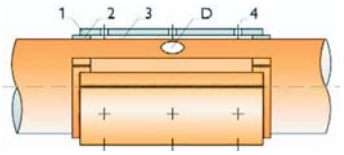
2. Theoretical part

2.1. Permanent repair of defects at gas pipelines with using steel sleeves

The Steel Repair Sleeves can be used for permanent repairing of high pressure gas, pipeline defects without interrupting. With using these repair methods, we can repair defects, such as internal and external corrosion, gouges, dents, grooves, arc burns, cracks, defective girth welds, laminations and leaks [1].

The steel sleeve is composed of segmented steel casing, fitted on two steel distance rings, which defines the space between the sleeve and the repaired pipe. This space is filled with glass beads and epoxy (composite). Cured epoxide, provides a perfect transmission of stresses from pipeline to sleeve. Type of material and thickness sleeve and distance rings, must be same as the thickness of the repaired pipeline. Epoxy obtains desired mechanical properties after 24 hours curing. Good space filling composites are checked through the inspection holes [1].

Depending on the seriousness and type of defect on the pipeline sleeves can be divided to:
- cold sleeve – steel casing fitted on two steel distance rings is welded only longitudinal butt weld,
- hot sleeve – steel casing fitted on two steel distance rings is welded longitudinal butt weld and also is welded with fillet weld to distance rings [1].



1 – steel segmented sleeve
2 – distance rings
3 – composite
4 – inspection holes
D – pipeline defect
++ – weld

Fig. 1 Steel repair sleeve [1]

2.2. SYSWELD

SYSWELD is a Finite Element software that simulates all usual welding processes such as MMA, MIG, TIG, spot welding, laser welding, heat treatment like bulk hardening, surface hardening, tempering and hardening and tempering, as well as thermo-chemical treatment like case hardening, carbonitriding, nitriding [2].

The software calculates dimensional variations and distortions of parts, hardness, strength and strain at break of the material in use, plus residual stresses, during and at the end of the welding or heat treatment process [2].

Simulation of a welding process requires two successive analyses:
- first a thermo-metallurgical analysis,
- followed by a mechanical analysis.

2.2.1 Definition of heat source in SYSWELD

Temperature $T(x,y,z,t)$ is function of coordinates in volume and time. Precious determination of temperature field during welding

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(that means mainly shape and size of heat affected zone) is first and very important step for real determination of right material structure. Therefore finding the right mathematical description for heat source is very important for numerical simulations.

Simulation system SYSWELD used for numerical calculations of heat following heat sources: 2D Gaussian model – for surface thermal treatment of material, 3D Gaussian model – for simulation of welding with high power density in impact area and 3D Glodak model – for shielded metal arc welding, submerged arc welding, GTAW, GMAW. Just because of great using variability will be this type of heat source closely described [3].

2.2.2 Goldak model of heat source

This type of heat source can be used for most of fusion welding conventional methods. Combination of two interlocking ellipsoids describes best real state so far. By contrast to previous heat source is double-ellipsoid heat source described by two equations individually for each ellipsoid. Compared to ellipsoid heat source there are in following equations parameters f_1 and f_2. These are constants which influence energy flow intensity into material (into individual ellipsoids) and for them the following equation has to be valid:

$$f_1 + f_2 = 2 \tag{1}$$

Double-ellipsoid heat source is shown in Fig. 2 and is described by following equations (2) and (3).

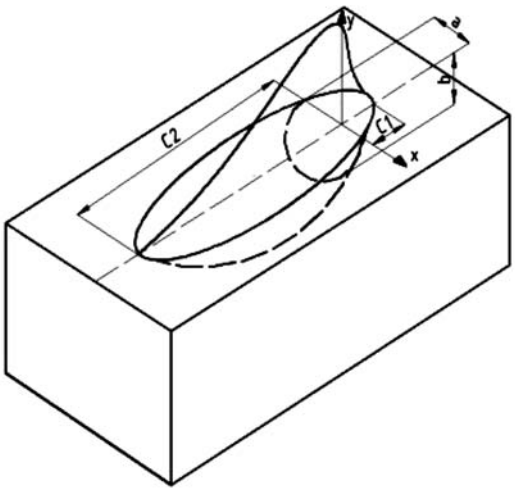


Fig. 2 Goldak double ellipsoidal heat source model [3]

$$q(y, x, \xi) = \frac{6 \cdot \sqrt{3} \cdot f_1 \cdot Q \cdot \eta}{a \cdot b \cdot c_1 \cdot \pi \cdot \sqrt{\pi}} \cdot e^{\frac{-x^2}{a^2}} \cdot e^{\frac{-y^2}{b^2}} \cdot e^{\frac{-\xi^2}{c_1^2}} \tag{2}$$

$$q(y, x, \xi) = \frac{6 \cdot \sqrt{3} \cdot f_2 \cdot Q \cdot \eta}{a \cdot b \cdot c_2 \cdot \pi \cdot \sqrt{\pi}} \cdot e^{\frac{-x^2}{a^2}} \cdot e^{\frac{-y^2}{b^2}} \cdot e^{\frac{-\xi^2}{c_2^2}} \tag{3}$$

Where location of heat source is given by equation:

$$\xi = z_k - v \cdot (\tau - t) \tag{4}$$

where:

$q(x, y, \xi)$	– heat flow density into material, [W.m^{-3}]
Q	– overall heat, [W]
a, b ,$c_{1,2}$	– coordinates of fusion zone, [m]
x, y, z	– coordinates of point, [m]
f_1,f_2	– constants influencing energy flow intensity distribution into material, [–]
η	– heat source efficiency, [–]
τ	– overall welding time, [s]
t	– instantaneous welding time, [s]
v	– welding velocity, [m.s^{-1}]
ξ	– location of heat source in dependence on welding time, [m]
z_k	– z-coordinate at the close of welding [3].

3. Experimental part

This experiment includes analysis of boundary conditions for the simulation of welding in the repair of gas pipelines with steel sleeve.

3.1. Experimental sample

Model used for the experiment was compounded of two 60° pipe sections of materials L360NB (pipe and distance ring). Pipe has a diameter of 323.9 mm, pipe's thickness is 10mm and length 260 mm. Distance ring has a diameter of 333.9 mm, ring thickness 10 mm and length 90 mm. Welding joint was welded using the MMA process. Experimental sample was welded with two fillet passes of weld. These two layers are only part of the finished weld.

3.2. Experimental measurements during and after welding

During welding were measured welding parameters, welding time and thermal cycles in three points. After welding the weld was analysed. Complete analysis of the weld for simulation in simulation programme SYSWELD contains:

Parameters of welding. Tab. 1.

Parameters of welding				
Weld	U_w [V]	I_w [A]	s_w [mm.s^{-1}]	Q_r [J.cm^{-1}]
Weld 1	23.6	92	2.2	7895
Weld 2	23.6	92	2.25	7719

U_w – welding voltage
I_w – welding current
s_w – welding speed
Q_r – real heat input (η = 0.8)

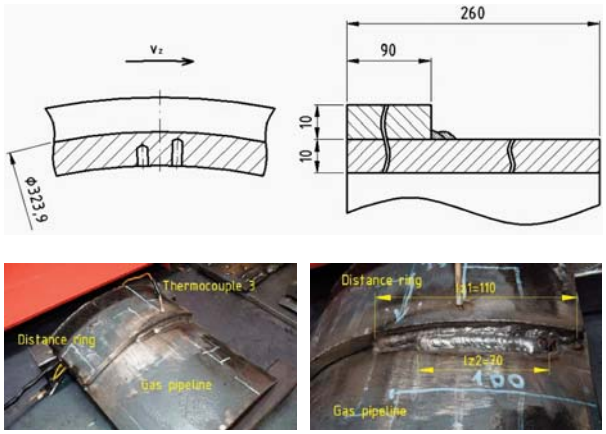


Fig. 3 Experimental sample, scheme (up), real sample (down)

- parameters of welding (U_w, I_w),
- cross-sectional geometry of the welds (weld metal, heat affected zone),
- welding speed (s_w),
- thermal cycles.

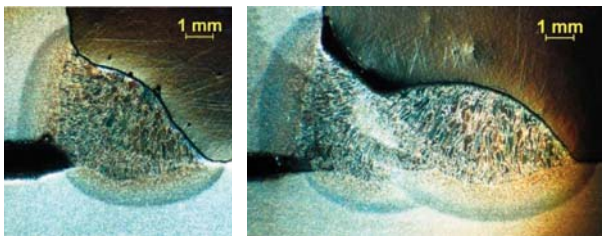
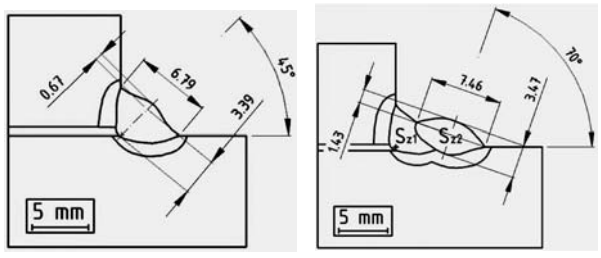


Fig. 4 Macrostructural analysis

Digitizing the weld macrostructures, we get cross-sectional parameters of welds (Fig. 5.), which are necessary for the definition of Goldak heat source model.



S_{z1} = 17,2 mm^2 - weld area
S_{z2} = 16 mm^2

Fig. 5 Cross-sectional parameters of the weld

Temperature cycles were measured by three thermocouples. Their location is shown in Fig. 6.

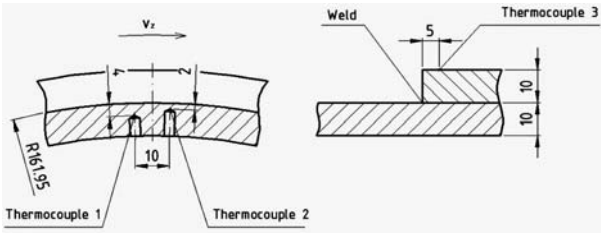


Fig. 6 Location of thermocouples

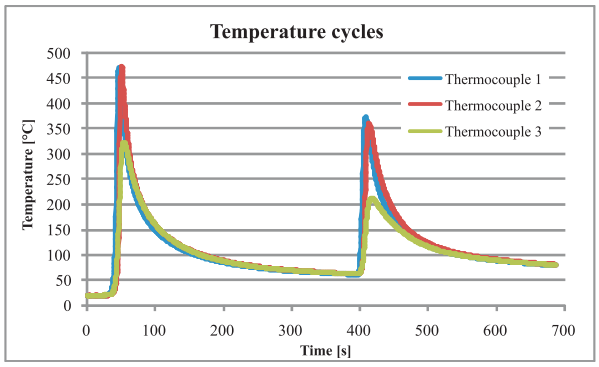


Fig. 7 Temperature cycles in three thermocouples

Characteristic attributes of temperature cycle Tab. 2.

Characteristic attributes of temperature cycles			
1. pass of weld			
Thermocouple	T_{max} [°C]	$r300$ [°C.s^{-1}]	$t100$ [s]
1.	465	9.78	113
2.	480	10.6	117
3.	322	6.5	112
2. pass of weld			
Thermocouple	T_{max} [°C]	$r300$ [°C.s^{-1}]	$t100$ [s]
1.	373	8.7	136
2.	360	8.5	144
3.	212	-	126

3. Conclusion

Experimental results will serve as a boundary condition for the simulation in simulation programme SYSWELD. The simulation process will provide information about residual stresses arising in the repair of gas pipelines with steel sleeve.

Acknowledgement

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Robert Bednar – Milan Saga – Milan Vasko *

EFFECTIVITY ANALYSIS OF CHOSEN NUMERICAL METHODS FOR SOLUTION OF MECHANICAL SYSTEMS WITH UNCERTAIN PARAMETERS

The paper deals with usability and efficiency problem for the chosen solution methods for mechanical systems with structural uncertainties, which are significantly influencing the analysis results and the analysis itself. In the centre of interest will be the chosen approaches and methods. An application of the chosen approaches is presented – the first one, a simple combination of only inf-values or only sup-values; the second one presents full combination of all inf-sup values; the third one uses the optimizing process as a tool for finding out an inf-sup solution and last one is Monte Carlo technique as a comparison tool.

Keywords: *uncertain parameters, MATLAB, Monte Carlo, interval arithmetic, optimization*

1. Introduction

Generally, it is possible to say that each engineering problem encounters uncertainties in various forms, e.g. geometrical parameters, material constants, loads, etc. Many of those uncertainties are based on physical imperfections; the general diversity and complexity of natural phenomena and, of course, our ignorance or inability to precisely describe characteristics of the investigated problem.

Uncertain parameters appear mostly as random variables and thus are described in the terms of stochastic approach. But without the knowledge of the probability density and the nature of distribution we are forced to use another approach, which could describe the parameters with the mentioned restrains and at the same time contain sufficient information about the character of the uncertainty.

Alternately to the use of probability methods we can use imprecise probabilities and the possibility theory, which involves the theory of interval numbers [2, 3, 4], fuzzy numbers and fuzzy sets [5, 6, 9]. Without the information of the relevance of the data on the interval, we cannot use the fuzzy approach, but we are still able to use the interval approach to describe the uncertain parameters which are considered as unknown but bounded with lower and upper bounds.

Our short study proposes algorithms for modal and spectral interval computations of FE models and their effectivity analysis in view of the input uncertainty degree (2%, 5%, 10%, 15%, 20%).

2. Computational methods for interval analysis

If we want to use interval arithmetic approach, an uncertain number is represented by an interval of real numbers [2, 4]. The interval numbers derived from the experimental data or expert knowledge can then take into account the uncertainties in the model parameters, model inputs etc. Complete information about the uncertainties in the model may be included by this technique and one can demonstrate how these uncertainties are processed by the calculation procedure in MATLAB.

During the solving of the particular tasks using the interval arithmetic application on the solution of numerical mathematics and mechanical problems, the problem known as the overestimate effect is encountered. Its elimination is possible only in the case of meeting the specific assumptions, mainly related to the time efficiency of the computing procedures [1, 3]. Considering uncertain parameters in interval form, some solution approaches already used or proposed by the authors are analyzed [9, 11]. The goal is to present algorithm description and comparison study of the following numerical methods:

- Monte Carlo method (MC) - as a comparison tool,
- a simple combination of only inf-values or only sup-values (COM1),
- a full combination of all inf-sup values (COM2),
- a method which uses an optimization process as a tool for finding out a inf-sup solution (OPT).

Monte Carlo method (MC) is a time consuming but reliable solution. Various combinations of the uncertain parameter deter-

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ministic values are generated and after the subsequent solution in the deterministic sense we obtain a complete set of results processed in an appropriate manner. Infimum and supremum calculation is following

$$\begin{aligned} &\inf(F) = \text{min of all results } F(p_i), \\ &\text{where } i = 1, ..., m \text{ and } m \approx 5000 \div 100000 \\ &\sup(F) = \text{max of all results } F(p_i), \\ &\text{where } i = 1, ..., m \text{ and } m \approx 5000 \div 100000. \end{aligned} \tag{1}$$

Solution evaluation in marginal values of interval parameters (COM1) has its physical meaning for many engineering problems. We consider an approach where the extreme output values are obtained by the application of the extreme parameter values on input. That means that the inf-sup is obtained using the deterministic analysis for inf or sup of input uncertain parameters. Inf-sup calculation is

$$\begin{aligned} &\inf(F) = \text{min of } [F(\underline{p}), F(\overline{p})] \text{ and} \\ &\sup(F) = \text{max of } [F(\underline{p}), F(\overline{p})]. \end{aligned} \tag{2}$$

Solution evaluation for all marginal values of interval parameters (COM2) which is also based on the set of the deterministic analyses appears as the more suitable one. The marginal interval parameter values are considered again but the inf and sup values are also combined. The method provides satisfying results and can be marked as reliable, even if there is still a doubt about the existence of the extreme solution for the uncertain parameter inner values. Solution for two interval numbers $p_1 = \langle a_1\ b_1\rangle$ and $p_2 = \langle a_2\ b_2\rangle$ may be found by this computational way

$$\begin{aligned} &\inf(F) = \text{min of } F[(a_1\ a_2), F(a_1\ b_2), F(b_1\ a_2), F(b_1\ b_2)] \\ &\sup(F) = \text{max of } F[(a_1\ a_2), F(a_1\ b_2), F(b_1\ a_2), F(b_1\ b_2)] \end{aligned} \tag{3}$$

The method of the inf and sup solution using the optimization techniques (OPT) is proposed by the authors as an alternative to the first and to the third method. It should eliminate a big amount of analyses in the first method and also eliminates the problem with the possibility of the inf and sup existence inside of the interval parameters for the deterministic values. Computational process for two interval numbers p_1 and p_2 may be found as follows

$$\begin{aligned} &\inf(F) = F(\boldsymbol{p}_{OPT}), \text{ i.e. find } \boldsymbol{p}_{OPT} \text{ so that } F(\boldsymbol{p}_{OPT}) \to \min, \\ &\sup(F) = F(\boldsymbol{p}_{OPT}), \text{ i.e. find } \boldsymbol{p}_{OPT} \text{ so that } F(\boldsymbol{p}_{OPT}) \to \max, \end{aligned} \tag{4}$$

3. Interval analysis of a damped computational model

A numerical analysis of the damped computational model (Fig. 1) with uncertain parameters (damping parameter, stiffness parameter, etc.) in interval form will be presented. The interval modal-spectral analysis in the range of the first three eigen shapes was performed. The mechanical system represents half of a vehicle under vertical excitation of the front and rear axle.

It is assumed that the model is linearized about the operating state and that the coordinates $z_{1V}(t)$, $z_{1H}(t)$, $z_2(t)$, $\varphi_2(t)$ and $z_3(t)$ are measured from the equilibrium state [3]. The coordinates $z_{2V}(t)$ and $z_{2H}(t)$ can be described as functions of the geometry of the model and the coordinates $z_2(t)$ and $\varphi_2(t)$.

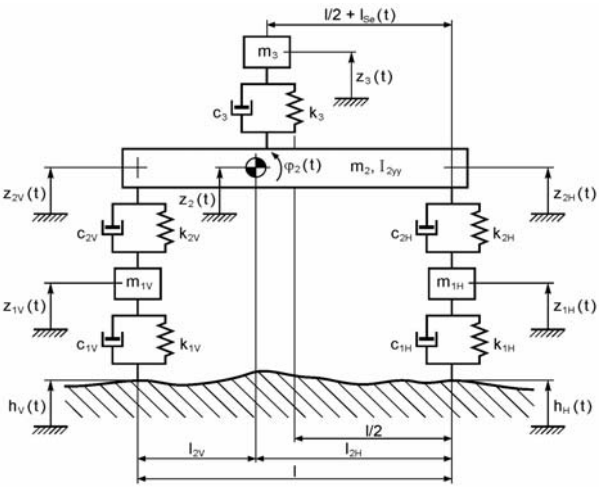

Fig. 1 5-DOF spring-mass-dashpot system

Mathematical model

As mentioned in previous section, the state space model for the mathematical description is used [7, 8]. The state vector $\boldsymbol{x}(t)$ and the input vector $\boldsymbol{u}(t)$ for the two wheels of the system can be given as

$$\begin{aligned} \boldsymbol{x}(t) &= \left[z_{1V}(t)\, z_{1H}(t)\, z_2(t)\, \varphi_2(t)\, z_3(t)\, \dot{z}_{1V}(t)\, \dot{z}_{1H}(t)\right. \\ &\left.\dot{z}_2(t)\, \dot{\varphi}_2(t)\, \dot{z}_3(t)\right]^T \text{ and } \boldsymbol{u}(t) = \begin{bmatrix} h_V(t) \\ h_H(t) \\ \dot{h}_V(t) \\ \dot{h}_H(t) \end{bmatrix}. \end{aligned} \tag{5}$$

For easier representation, the state matrix $\boldsymbol{A}$ of the given system can be decomposed in four sub matrices, i.e.,

$$A = \begin{bmatrix} 0 & I \\ -M_S^{-1}K_S & -M_S^{-1}C_S \end{bmatrix}. \tag{6}$$

The matrix $\mathbf{0}$ is a 5-by-5 zero matrix and $\boldsymbol{I}$ represents a 5-by-5 identity matrix. The mass matrix $\boldsymbol{M}_S$ has five entries along the main diagonal which are not zero

$$M_S = \begin{bmatrix} m_{1V} & 0 & 0 & 0 & 0 \\ 0 & m_{1H} & 0 & 0 & 0 \\ 0 & 0 & m_2 & 0 & 0 \\ 0 & 0 & 0 & I_{2_{yy}} & 0 \\ 0 & 0 & 0 & 0 & m_3 \end{bmatrix}. \tag{7}$$

The stiffness matrix $\boldsymbol{K}_S$, a 5-by-5 matrix consisting of the corresponding stiffness coefficients

$$K_S = \begin{bmatrix} k_{1V}+k_{2V} & 0 & -k_{2V} & k_{2V}l_{2V} & 0 \\ 0 & k_{1H}+k_{2H} & -k_{2H} & -k_{2H}l_{2H} & 0 \\ -k_{2V} & -k_{2H} & k_{2H}+k_{2V}+k_3 & k_{3.4} & -k_3 \\ k_{2V}l_{2V} & -k_{2H}l_{2H} & k_{4.3} & k_{4.4} & -k_3(l/2-l_{2V}-l_{Se}) \\ 0 & 0 & -k_3 & -k_3(l/2-l_{2V}-l_{Se}) & k_3 \end{bmatrix}. \quad (8)$$

with

$$\begin{aligned} k_{3,4} &= k_3(l/2 - l_{2V} - l_{Se}) \\ k_{4,3} &= k_3(l/2 - l_{2V} - l_{Se}) \\ k_{4,4} &= k_3(l/2 - l_{2V} - l_{Se})^2 + k_{2H}l_{2H}^2 + k_{2V}l_{2V}^2 \end{aligned} \quad (9)$$

Similar to the stiffness matrix $\boldsymbol{K}_S$, the damping coefficient matrix $\boldsymbol{C}_S$, also a 5-by-5 matrix is given as

4. Solving of truss structure with interval parameters

Considering different uncertain parameters the numerical interval stress-strain study of a three-dimensional truss structure (Fig. 5) was performed.

As the interval uncertain parameters were the cross-sections of the trusses considered. Because of the computation memory and time demands, fifty one bars were split into 7 cross-sectional groups (Fig. 6) [10]. All other parameters were considered as certain.

$$C_S = \begin{bmatrix} c_{1V}+c_{2V} & 0 & -c_{2V} & c_{2V}l_{2V} & 0 \\ 0 & c_{1H}+c_{2H} & -c_{2H} & -c_{2H}l_{2H} & 0 \\ -c_{2V} & -c_{2H} & c_{2H}+c_{2V}+c_3 & c_{3.4} & -c_3 \\ c_{2V}l_{2V} & -c_{2H}l_{2H} & c_{4.3} & c_{4.4} & -c_3(l/2-l_{2V}-l_{Se}) \\ 0 & 0 & -c_3 & -c_3(l/2-l_{2V}-l_{Se}) & c_3 \end{bmatrix}. \quad (10)$$

with

$$\begin{aligned} c_{3,4} &= c_3(l/2 - l_{2V} - l_{Se}) \\ c_{4,3} &= c_3(l/2 - l_{2V} - l_{Se}) \\ c_{4,4} &= c_3(l/2 - l_{2V} - l_{Se})^2 + c_{2H}l_{2H}^2 + c_{2V}l_{2V}^2 \end{aligned} \quad (11)$$

Percentage variances for real and imaginary parts of 1st, 2nd and 3rd eigenvalues are shown on Figs. 2-4. The MC, COM2 and OPT methods were used for the interval modal-spectral analysis.

Certain parameters: $E = 2 \cdot 10^{11}$ Pa, $\mu = 0.3$, $\rho = 7800$ kg $\cdot$ m^{-3}, $\delta = 10^{-5}$.

Uncertain parameters: $xf = [0.02, 0.05, 0.10, 0.20]$,

$A_1 = 3500 \cdot 10^{-6} \cdot (1 + xf_i)$ m^2,
$A_2 = 3000 \cdot 10^{-6} \cdot (1 + xf_i)$ m^2,
$A_3 = 2500 \cdot 10^{-6} \cdot (1 + xf_i)$ m^2,
$A_4 = 2000 \cdot 10^{-6} \cdot (1 + xf_i)$ m^2,
$A_5 = 1800 \cdot 10^{-6} \cdot (1 + xf_i)$ m^2,
$A_6 = 1500 \cdot 10^{-6} \cdot (1 + xf_i)$ m^2,
$A_7 = 1000 \cdot 10^{-6} \cdot (1 + xf_i)$ m^2.

Values for the parameters of the 5-DOF spring-mass-dashpot system — Tab. 1.

Uncertain parameters			Certain
Mass parameters	Stiffness constants	Damping coefficients	Distances
$m_{1V} = 45 \cdot (1 + xf_i)$ kg	$k_{1V} = 230 \cdot 10^3 \cdot (1 + xf_i)$ N/m	$c_{1V} = 46 \cdot (1 + xf_i)$ Ns/m	$l_{2V} = 1.8$ m
$m_2 = 632.5 \cdot (1 + xf_i)$ kg	$k_{1H} = 230 \cdot 10^3 \cdot (1 + xf_i)$ N/m	$c_{1H} = 5 \cdot (1 + xf_i)$ Ns/m	$l_{2H} = 2.2$ m
$m_{1H} = 37 \cdot (1 + xf_i)$ kg	$k_{2V} = 22.6 \cdot 10^3 \cdot (1 + xf_i)$ N/m	$c_{2V} = 1900 \cdot (1 + xf_i)$ Ns/m	$l_{Se} = 2$ m
$m_3 = 28 \cdot (1 + xf_i)$ kg	$k_{2H} = 20 \cdot 10^3 \cdot (1 + xf_i)$ N/m	$c_{2H} = 1900 \cdot (1 + xf_i)$ Ns/m	$l = 4$ m
$I_{2yy} = 773.5 \cdot (1 + xf_i)$ kg.m^2	$k_3 = 9.9 \cdot 10^3 \cdot (1 + xf_i)$ N/m	$c_3 = 260 \cdot (1 + xf_i)$ Ns/m	

where $xf = [0.02, 0.05, 0.08, 0.10, 0.12, 0.15, 0.18, 0.20]$.

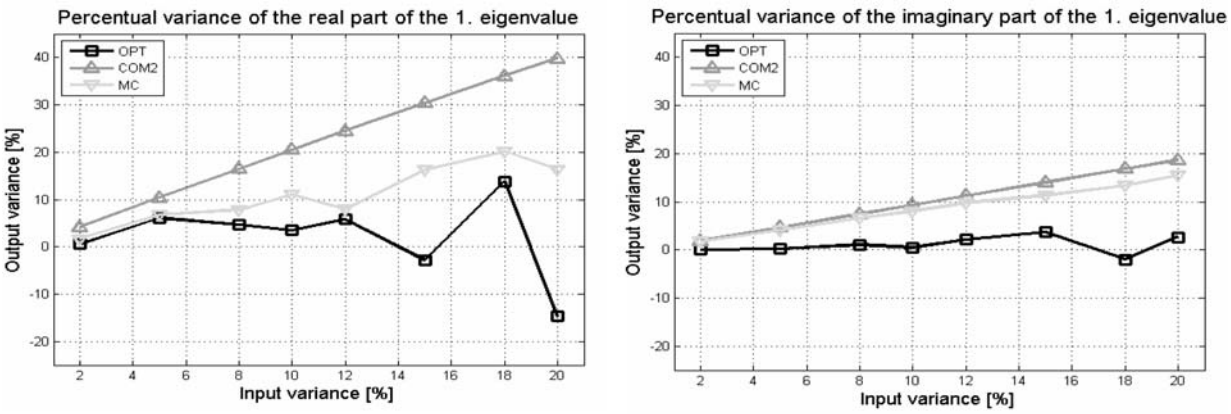

Fig. 2 Percentage variance of the 1st eigenvalue

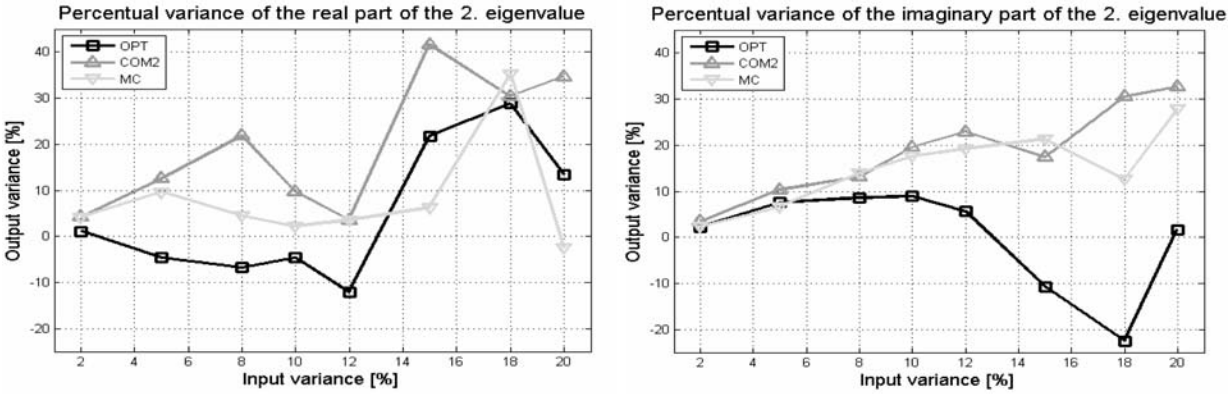

Fig. 3 Percentage variance of the 2nd eigenvalue

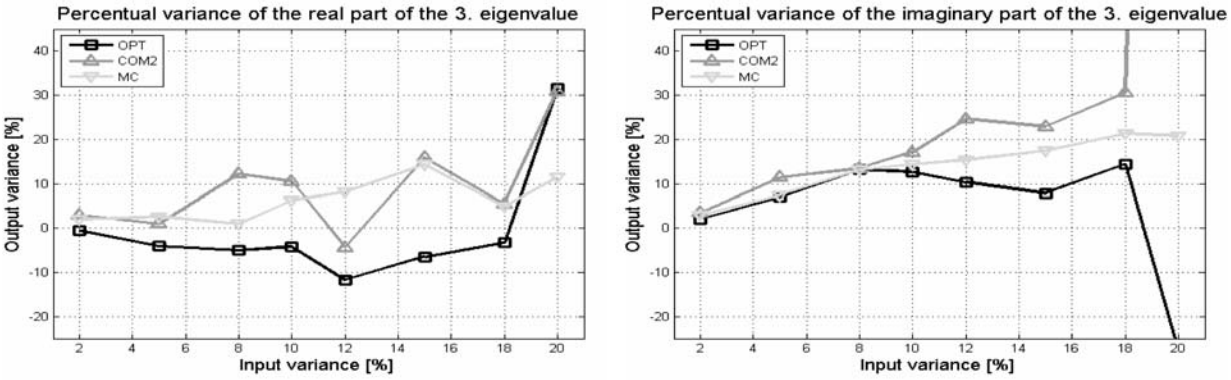

Fig. 4 Percentage variance of the 3rd eigenvalue

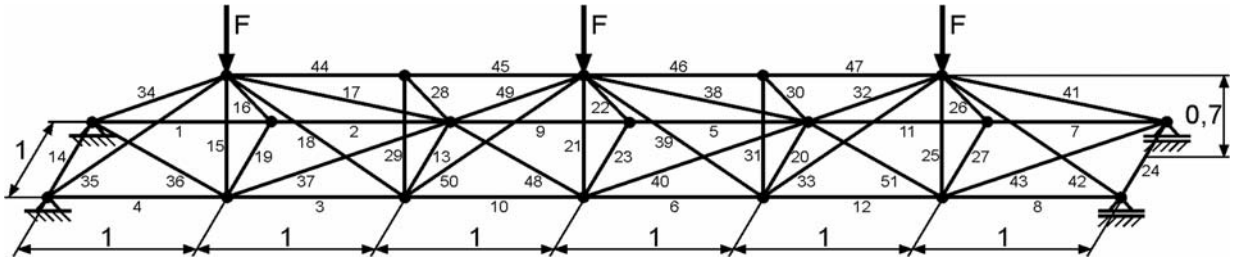

Fig. 5 Analyzed truss structure, dimensions in [m]

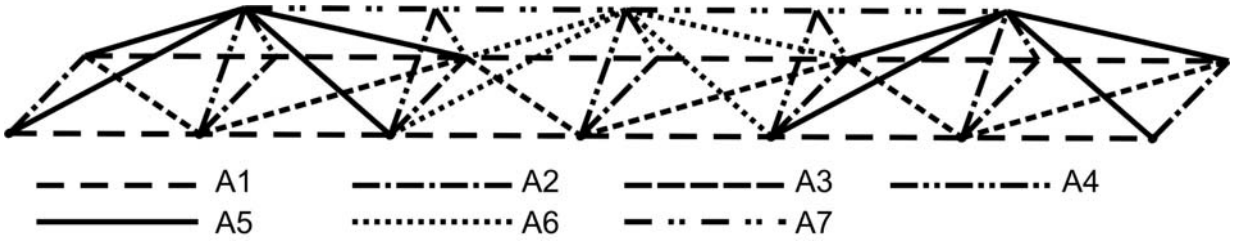

Fig. 6 Truss structure split into 7 cross-sectional groups

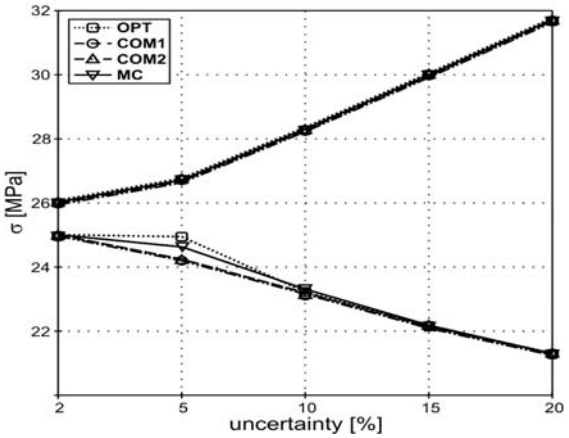

Fig. 7 Stress solution on beam No. 5

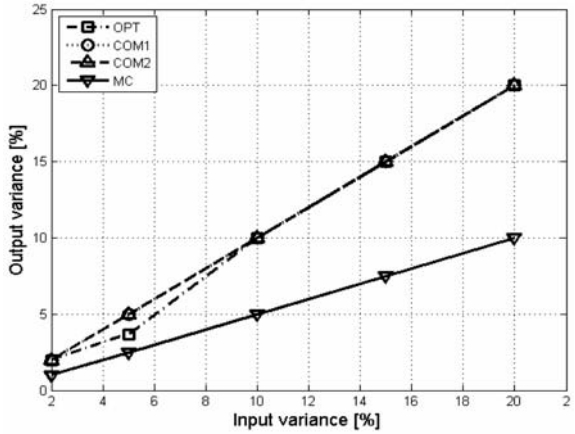

Fig. 8 Percentage variance on beam No. 5

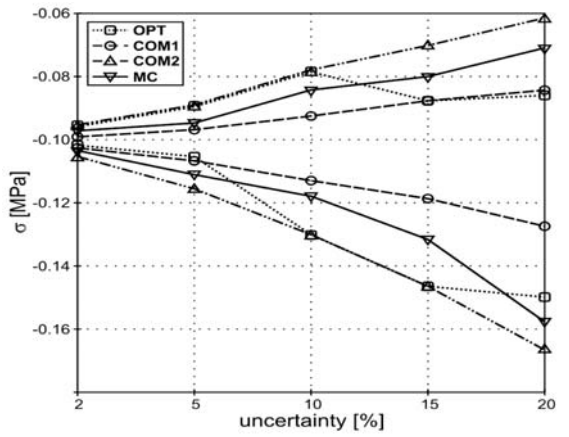

Fig. 9 Stress solution on beam No. 36

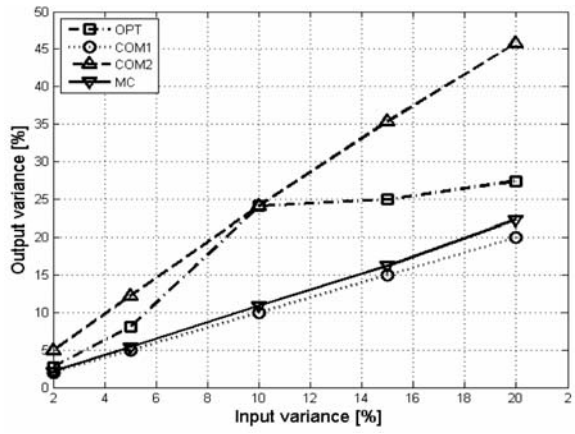

Fig. 10 Percentage variance on beam No. 36

Stress inf/sup results for the chosen bars [MPa] Tab. 2.

Uncertainty	Bar No.	MC	OPT	COM1	COM2
2%	5	⟨ 25.010 26.030 ⟩	⟨ 25.010 26.030 ⟩	⟨ 25.010 26.030 ⟩	⟨ 25.010 26.030 ⟩
	36	⟨ −0.104 −0.097 ⟩	⟨ −0.102 −0.096 ⟩	⟨ −0.103 −0.099 ⟩	⟨ −0.106 −0.096 ⟩
5%	5	⟨ 24.754 26.853 ⟩	⟨ 24.946 26.853 ⟩	⟨ 24.295 26.853 ⟩	⟨ 24.295 26.853 ⟩
	36	⟨ −0.110 −0.095 ⟩	⟨ −0.106 −0.090 ⟩	⟨ −0.107 −0.097 ⟩	⟨ −0.115 −0.090 ⟩
10%	5	⟨ 23.264 28.345 ⟩	⟨ 23.191 28.345 ⟩	⟨ 23.191 28.345 ⟩	⟨ 23.191 28.345 ⟩
	36	⟨ −0.118 −0.085 ⟩	⟨ −0.130 −0.079 ⟩	⟨ −0.113 −0.092 ⟩	⟨ −0.130 −0.079 ⟩
20%	5	⟨ 21.258 31.888 ⟩	⟨ 21.258 31.888 ⟩	⟨ 21.258 31.888 ⟩	⟨ 21.258 31.888 ⟩
	36	⟨ −0.158 −0.071 ⟩	⟨ −0.150 −0.086 ⟩	⟨ −0.127 −0.085 ⟩	⟨ −0.167 −0.062 ⟩

5. Conclusion

The paper presents the interval arithmetic application on structural FE analysis and on a modal and spectral analysis. The interval arithmetic provides a new possibility of the examination of quality and reliability of analyzed objects. In the paper authors investigated possibilities of the stress-strain solution of models with interval cross-sectional areas of the truss structure.

It shows the solution efficiency for solving problems including uncertain parameters with a various width of the interval. The interval arithmetic was chosen as a tool for describing various uncertain characteristics of a damped mechanical model. The solution efficiency for solving problems including uncertain parameters with a various width of the interval is shown.

The presented analyses results can be summarized as follows:

- MC is a sure method for obtaining adequate solution results, with the regard of the amount of analyses needed,
- COM1 method gives satisfactory results and can be described as reliable for this kind of analyses, although doubt arises in the sense of the existence of extreme solution for inner values of uncertain parameters,
- COM2 method provides decent results, but it is limited due to the exponential growth of the analyses number for complicated problems, once again arises doubt in the sense of existence of extreme solution for inner values of uncertain parameters,
- OPT method provides good results and is suitable for complicated problems because it does not need so many analyses as in the cases of the MC or COM2 methods.

Acknowledgement

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ANALYSIS OF THE BEHAVIOUR OF STEEL-CONCRETE COMPOSITE TRUSS

The design specifications of composite truss, included in the American standard (ASCE), are not covered in the European standards (Eurocodes). In this study, to investigate the behaviour of the composite trusses, a finite element model (FEM) is developed using the software CAST3M. The influence of various parameters, such as the diameter of the shear connectors, the degree of connection, the top chord section and the material characteristics on the behaviour of the composite truss and the shear connectors are analyzed. The model shows that the shear connection in the steel-concrete composite truss reduces its deflection by approximately 50 % in comparison with the steel truss. The significant influence of the top chord section on the shear forces in the shear connectors was observed.

Keywords: *FEM Analysis, Top Chord Section, Shear Connectors, Shear Force.*

1. Introduction

Composite steel-concrete construction is one of the most economical systems for building and bridge floors, especially for greater spans. To mobilize the efficiency of concrete in compression and steel in tension it is necessary to prevent the relative slip between the concrete and the steel element using the shear connectors. Different types of shear connectors are used nowadays. This concerns the welded headed studs, the Hilti brackets and the welded perforated shear connectors [1] [2]. In some situations, such as with precast concrete slab or to develop composite action in non-composite structures, shear connection is developed using bolts [3] [4].

Composite systems give the possibility to get spans up to 20 m and the composite trusses are appropriate to meet the requirements for building height limitation, the need to run complex electrical, heating, ventilating, and communication systems and the even greater spans (30 m), which allows a better use of internal space without restricting columns.

Since the mid of 1960's, many investigations have been made in testing composite trusses mainly in USA and Canada, summarized in references [1] and [5]. The experimental results led to design recommendations and specification of the American Society of Civil Engineers (ASCE) [6].

In Eurocode EN 1994-2: 6.6.2.3 [7], there is no particular recommendation for the design of composite truss, except the formulas for the local effect of a concentrated longitudinal force and the distribution of the longitudinal shear force into local shear flow between steel section and concrete slab. In fact, the longitudinal forces are introduced into the concrete slab only locally at points of the increase of the axial force in the chord, i. e. where the web members are connected to the compressed chord (panel points).

In this study the influence of the degree of connection, represented by the connector diameter, the influence of the top chord section and the material characteristics of steel and concrete are analyzed pondering over the stiffness and the resistance of the beams and the shear forces in the connectors. The analysis is based on the finite element modeling.

2. FEM Model

For the analysis of the composite truss the software CAST3M is used. The geometry of the truss (Fig. 1) is chosen from the references [1] [2]. The top chord of the steel truss is designed as ½ IPE 220, the bottom chord is a rectangular hollow section RHS 60×60×4 and the web members are from RHS 50×50×3. The top chord of the truss is connected to the concrete slab (1500×80 mm) with headed studs connectors (Φ = 19 mm). All the components of the composite beam are modeled using beam elements with appropriate cross section. The web member elements are considered pin-ended but the chords are continuous.

The analysis was performed using the characteristic values of material properties. Simplified stress-strain diagrams of steel (S355) and concrete (C25/30) are shown in Fig. 2. The non-linear behaviour of the shear connection was modelled using beam elements uniformly distributed with a regular spacing equal to 100 mm along

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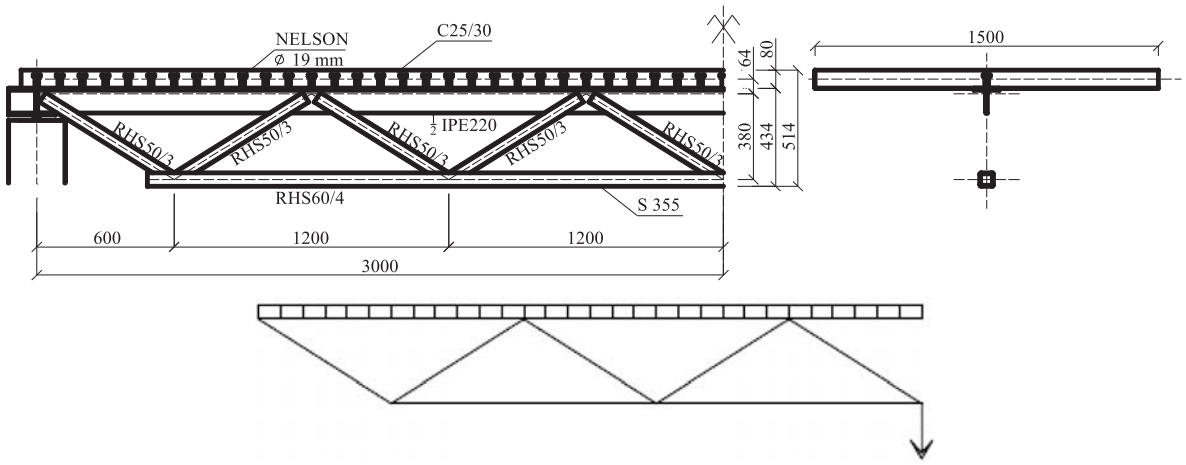

Fig. 1 Geometric characteristics of the composite truss and the FEM model

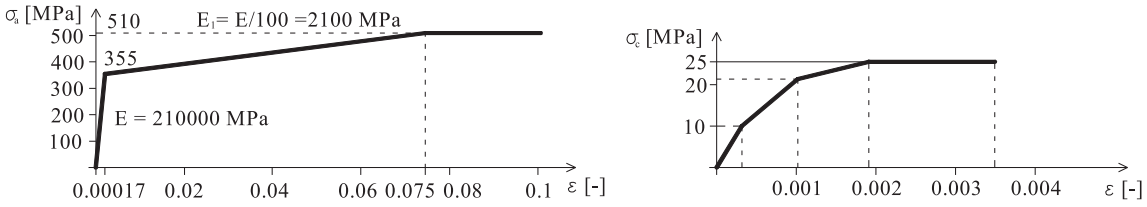

Fig. 2 Stress-strain curves of the steel and the concrete used in the FEM model

the span and located between the neutral axis of the top chord and the concrete slab [8]. In the model, virtual elastic-plastic material is used for the beam element in bending to represent the behaviour of the connection in shear. The uplift effects between the concrete slab and the beam element, prevented by the axial stiffness of the beam element representing the connector, are neglected in the model.

As the results of the push-out test of shear connectors were not available, the following formula of Ollgaard for stud shear capacity [9], based on the results of the push-out tests, was used.

$$P_{\max} = 0.336 A_d \sqrt{f_{ck} E_{cm}} \tag{1}$$

where A_d is the area of the shank of the stnd f_{ck} is the compressive cylinder strength of the concrete and E_{cm} is the secant modulus of the concrete.

The analytical expression of the evolution of the load – slip (P_i – s_i) curve is given by equation (2).

$$P_i = P_{\max}\left(1 - e^{-0.709 s_i}\right)^{0.4} \tag{2}$$

Loading of the truss was imposed at the central node of the bottom chord (Fig. 1). For elastic analysis, a load of 10 kN is applied and for plastic analysis the load is applied with a displacement control with a maximum value equal to 100 mm.

3. Results

In elastic analysis, the influence of the connectors is analyzed considering 360 theoretical values of diameter in the range 0.1 mm to 100 mm. These values represent the progression of the degree of shear connection in the truss from no connection to full connection. Their influence on the stiffness of the composite truss is shown in Fig. 3. It can be observed that the usual diameter of 19 mm is enough to obtain a full connection in the truss. Fig. 3 shows that the composite effect obtained by the shear connector diameter variation can increase even twice the stiffness of the truss with no connection and the truss composite beam with full connection.

The next investigation of the effect of the top chord section on the composite truss, included primarily its area A and the moment of inertia I. The chord varied from ½ IPE80 to ½ IPE600 (18 different sections). In this analysis a full connection is considered and the distance between the top chord and the bottom chord centroids remains constant. The value of the distance between the centroid of the top chord and that of the whole truss, when the top chord parameters A and I increase, becomes geater in the elastic analysis and decreases in the plastic analysis (Fig. 4). For the top chord

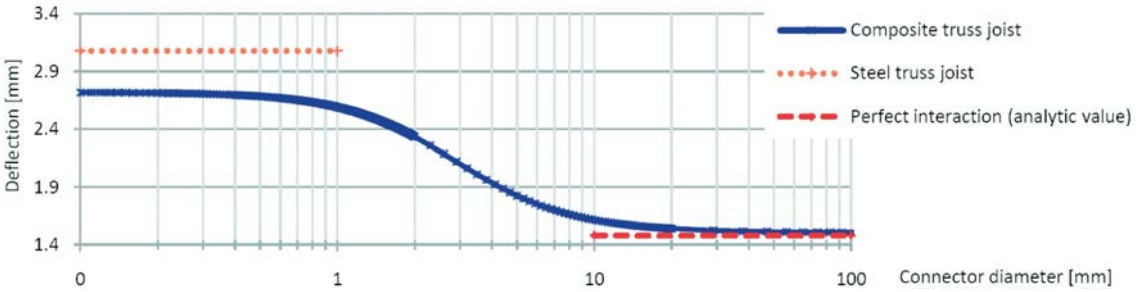

Fig. 3 Influence of the connector diameter on the deflection of the composite truss

section with $A < 6.7\times10^{-3}$ m^2 ($I < 4.6\times10^{-5}$ m^4) this distance and the contribution of the top chord to the resistance of the whole section are greater in plastic analysis than in elastic analysis. For the analyzed truss configuration, the contribution of the top chord on the resistance of the whole section is 7 % in elastic analysis and 10 % in plastic analysis. Therefore, in accordance with these results, the ASCE [6] neglects the global contribution of the top chord to the resistance of the whole section.

In Fig. 5, it can be seen that the influence of the top chord section on the stiffness of the truss damps down with the increase of the degree of connection for all types of the degrees of connection. This influence is more significant for lower degrees of connections (no connection or partial connection) with small chord sections (lower than 1.5×10^{-3} m^2). However for the real (and full) connection, the top chord section does not influence the stiffness of the composite truss significantly. The curves in Fig. 5 are drawn on the basis of the results of Fig. 3 where the full connection is represented by connector diameter of 50 mm, the real connection represented by the diameter 19 mm and the partial connection by the diameter 3 mm.

The distribution of the shear forces in the connectors along the beams, provided by plastic analysis and for the displacement equal to 100 mm is shown in Fig. 6 for different top chord sections. It can be observed that the plastic deformation of the connectors gives uniform distribution of shear forces along the beam. This

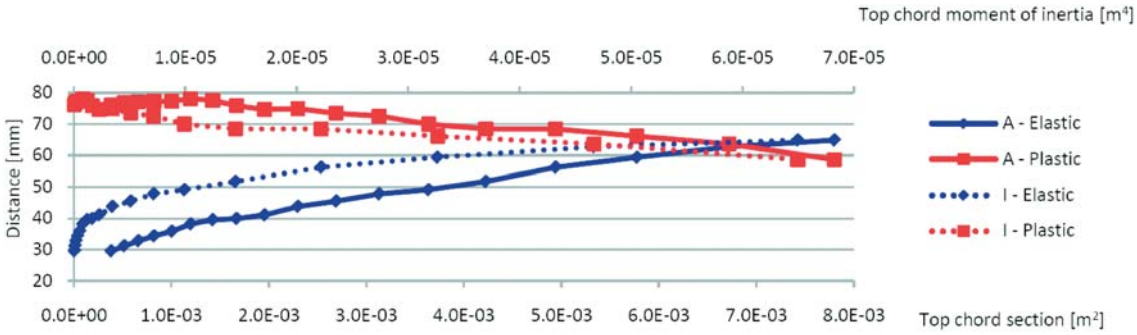

Fig. 4 Distance between the top chord and the composite truss centroids (⌀ 19 mm connectors)

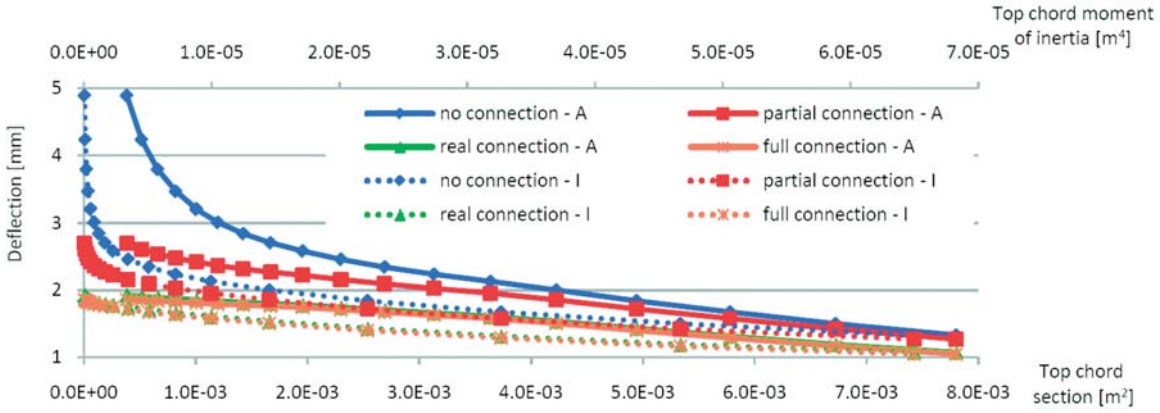

Fig. 5 Influence of the degree of connection on the stiffness of the truss

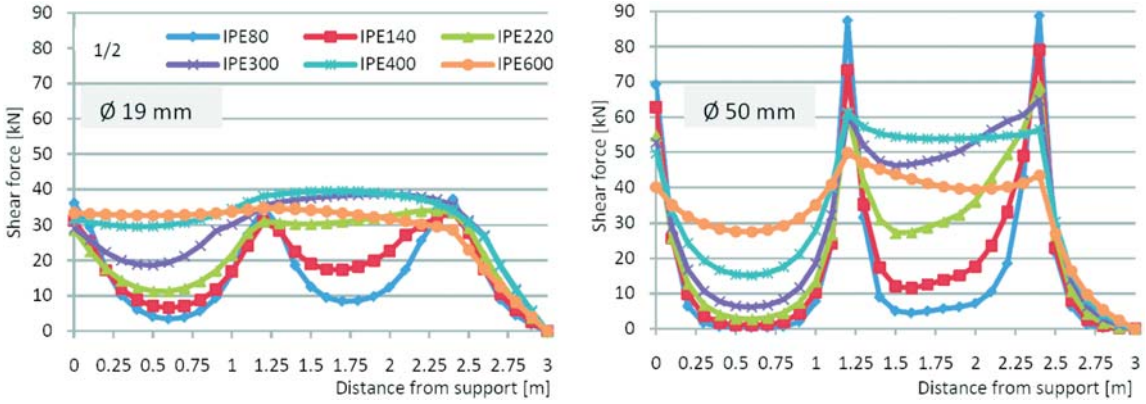

Fig. 6 Influence of the top chord section on the shear forces in the connectors (Ø 19 mm and 50 mm)

phenomenon is influenced by the ratio of geometry and resistance between the connector and the top chord section. Thus, it is necessary to optimize this ratio. Otherwise, the connectors in the panel area would transfer the predominant part of shear forces in comparison to the obvious zones on the chord between the nodes.

The influence of the material characteristics of concrete and structural steel on the distribution of shear forces in the connectors was analyzed in the additional parametrical study. The concrete strength is an input value in one of the formulae used to calculate the shear resistance of headed studs (1). Therefore, the greater value of concrete strength can provide a better shear force transfer in the connection. However the concrete strength does not affect significantly the shape of stress distribution by connectors (Fig. 7a). Impact of steel strength of truss material on the shear force distribution in the connectors (Fig. 7b) is small and can be neglected. However its influence on the resistance of the whole structure has to be considered.

4. Conclusion

The influence of different parameters of the steel-concrete composite truss on its behaviour was investigated by elastic and plastic analysis. The parametric studies showed that the top chord sections have no significant effect on the flexural stiffness and load carrying capacity of the composite trusses, because they are usually located very near to the neutral axis of the composite member. However, the top chord section has an important influence on values of the shear forces in the connectors. In fact, the ratio between the characteristics of the shear connector and the top chord section governs the distribution of shear force along the beam. It is necessary to optimize this ratio and to develop the rules for predicting the distribution of shear forces in the connectors for various ratios of shear connectors and top chord sections. In this way more efficient use of the connectors can be achieved.

The influence of material characteristics of the structure components presented the next subject of our study. It was found that concrete strength affect the connector resistance, but has no significant effect on the redistribution of shear forces in the connectors. Similarly, the steel strength of the truss has little influence on the shear forces in connection.

The improvement of this promising model is in progress on the basis of 3D model using solid elements and local damage evolution of concrete. The aim is to take account of the local phenomena such as the plastic deformation between the connectors and

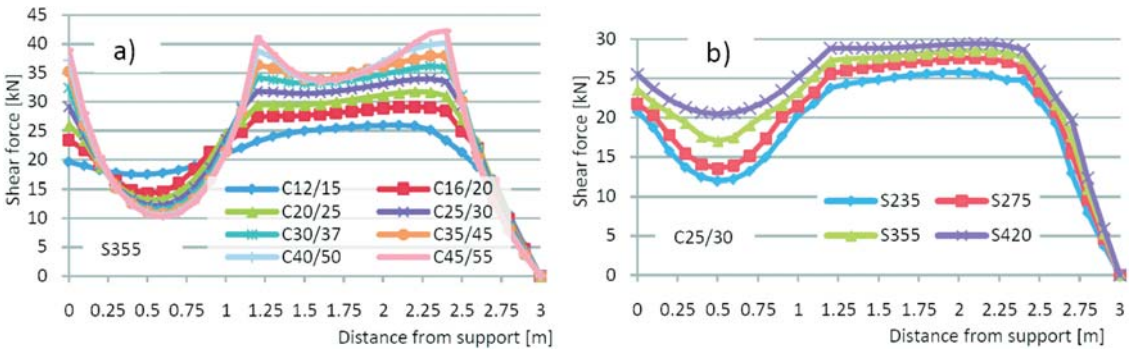

Fig. 7 Influence of material strength on the shear force distribution in the connectors: a) influence of the concrete strength of the slab, b) influence of the steel strength of the truss

the top chord on all the length of the chord including the panel points. The numerical model will be validated on the basis of experimental program including push-out tests and bending tests of composite trusses.

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Silvia Palajova – Milan Gregor *

SIMULATION METAMODELLING OF MANUFACTURING PROCESSES

This paper deals with models going out of simulation models, so called metamodels. They represent one of the possible ways how to increase effectiveness of simulation optimization, how to reduce the requirements of time-consuming simulation of manufacturing systems and how to make simulation cheaper. The heart of the paper describes steps of a metamodel making process and approximation of a real data using regression analysis and least square method.

Keywords: *simulation, metamodelling*

1. Introduction

Rapidly changing market environment and constantly new and higher requirements of demanding customers bring frequent type or volume product changes to the production. The main pressure from customers' side that manufacturer has to manage is the pressure for reducing costs, increasing efficiency and quality which is already commonplace nowadays. It is not possible to handle it, and simultaneously to touch competitive, without continuous improvement of factory processes, implementation of progressive management approaches, technologies, and without rapid decision-making of managers.

Currently, it is axiomatic to solve complex problems by an appropriate computer model that reflects characteristics of a real system or helps to find a solution close to optimal, or directly optimal, for existing or conceptual systems. Therefore, a computer simulation is still gaining major importance. It allows quick testing of various variants of solutions and it minimizes the risk of wrong decisions. This is reflected to considerable economic benefits. Simulation runs are usually computationally difficult and it is not unusual for complex simulation models that they last for hours. However, decision making support, exploratory analysis and rapid adaptive calculations often require simplicity for understanding and explanation of representations of reality. Therefore, there are often constructed simpler approximations – models of simulation model – or metamodels which are used for studying of a computer simulations' behavior.

2. Production process and its simulation

Production process (Fig. 1) is a set of activities that require one or more types of inputs and create output which has value to the customer. It is a chain of operations in which material is changed to the product or order to the service for the customer. [7] Currently, a flexibility of manufacturing process is required, which enables a company to respond flexibly to market demands. Except for shortening a production cycle, there are also requests for a high productivity, flexibility of product mix, various production programs, stock reducing, increasing of machine utilization, quality improvement, rapid responses to emerging problems, delivery time shortening, etc. Therefore, planning and control system has an important role in an enterprise.

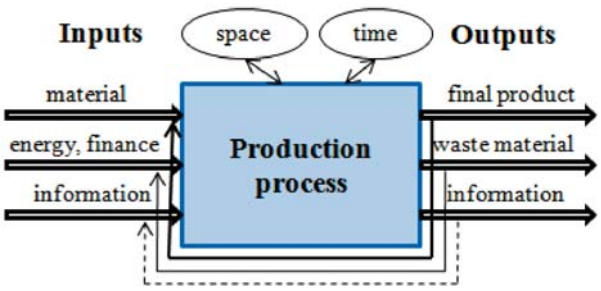

Fig. 1 Production process model

Qualitative information is provided by scheduling systems that enable forward simulation of possible options for future system's behavior and provide possibility of choice at the right moment. Such information is the base for an appropriate solution selection. Looking for optimal combination of input process factors needed for required changes execution is supported with simulation.

Simulation is a research method in which the experiments with a simulation model of manufacturing system are made on a com-

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puter. It also ranks among statistical methods because it works on the same theoretical basis as methods of mathematical statistic. The analyst conducting simulation experiments selects a sample (statistical sample) that represents characteristics of whole examined file. Such sample is statistically analyzed and the results are applied to the whole file (population). Similarly, simulation also replaces the real system with its simulation model. This model includes only those characteristics of real system which the analyst is interested in. After evaluation of results the analyst makes conclusions about the whole real system, based on experiments with the model [8].

For practical applications of simulation optimization it is important that the optimization process is constrained within reasonable time limits and the efficiency of the optimization process is crucial. One of the possible ways how to enhance effectiveness of simulation optimization and reduce the requirements of time-consuming simulation is to use computationally cheap metamodels [9].

3. Simulation metamodelling

Simulation metamodel [2] is a model of simulation model and it explains the fundamental nature of the system's input-output relationships through simple mathematical functions that enable to forecast output Y for given input X:

$$Y = \underbrace{f(X,\beta)}_{\eta} + \varepsilon \tag{1}$$

$Y = f(X, \beta)$ – regression function,
Y – dependent variable,
X – vector of values of input factors,
ε – vector of random numbers.

This relationship is the regression model that expresses free (stochastic) dependence between explanatory variables X and explaining variable Y. It means that for one particular combination of values of independent variables X may Y have various values. It is caused by an influence of random events ε. Thus, it is possible to assign count distribution of dependent variable Y, called conditional count distribution, which has its own mean and variance.

3.1. Regression model

According to the type of the regression function, regression models are divided into:

- linear models

$$y_i = \beta_0 + \beta_1 x_{i1} + \beta_2 x_{i2} + ... + \beta_k x_{ik} + \varepsilon_i \tag{2}$$

with linear regression function

$$\eta_i = \beta_0 + \beta_1 x_{i1} + \beta_2 x_{i2} + ... + \beta_k x_{ik} \tag{3}$$

where $\beta_0, \beta_1, ..., \beta_k$ are model parameters,

x_{ij} – i value ($i = 1, 2, ..., n$) of explanatory variable X_j ($j = 1, 2, ..., k$).

If the linear regression model has one independent variable ($k = 1$), the regression function is a line. If there are two explanatory variables ($k = 2$), the regression function is a plane. For more explanatory variables ($k \geq 2$), we are talking about hyperplane. Linear models are most commonly used.

- linear-able models that may be adjusted to the linear form by simple transformation:
  a) non-linear models in the independent variables but linear in parameters,
  b) non-linear models in the parameters,
- non-linear (no linear-able) models which cannot easily be transformed into a linear form. Their regression function is e.g. modified exponential curve:

$$\eta_i = \beta_0 + \beta_1 \cdot \beta_2^{x_i}, \tag{4}$$

logistic curve (S-curve that is symmetrical about an inflection point):

$$\eta_i = \frac{\beta_0}{1 + \beta_1 \cdot \beta_2^{x_i}}, \tag{5}$$

Gomperz's curve (S-curve that is asymmetrical about the inflection point):

$$\eta_i = \varepsilon^{\beta_0 + \beta_1 \cdot \beta_2^{x_i}}, \tag{6}$$

or curve with such recipe:

$$\eta_i = \sqrt{\beta_0 + \beta_1 x_{i1} + \beta_2 x_{i2}} + \beta_3 x_{i3}, \tag{7}$$

Regression analysis of nonlinear models uses different methods and procedures than linear models [10].

The aim purposes of regression and correlation analysis are [11]:

1. to verify the existence of dependence of explaining variable on considered explanatory variables,
2. evaluation of individual influence of explanatory variables on explaining variable,
3. forecasting explaining variable values for desired combinations of values of explanatory variables.

3.2. Metamodel making process

The metamodel creation (Fig. 2) begins with a simulation model which is preceded by defining the problem, defining the scope of input variables, the draft of the plan of experiments. After construction of a computer simulation model, its validation and verification is made, so logical structure of the model with respect to the real system is proved. Then a predefined number of replications for different input values is executed with the simulation model. In order to continue in metamodel making process we must be sure that data are sufficiently independent.

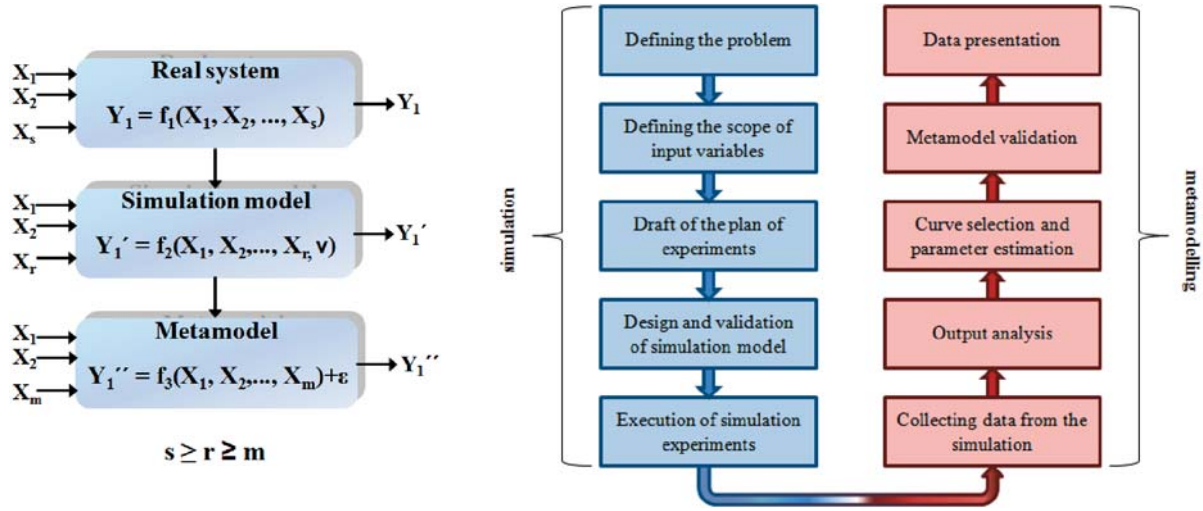

Fig. 2 Metamodel making process

In the next step, output data from the simulation are collected. In order to simplify the metamodel it is possible to combine some of the entries and remove those which have proved to be needless. These results are used for deriving a statistical model in the form of regression.

The heart of metamodelling is to determine a vector $\beta = (\beta_1, \beta_2, ..., \beta_p)^T$ which is a set of coefficients that determine regression function. Some of these coefficients, perhaps all, are unknown and they have to be estimated by adjusting the regression function to observed simulation results. The method of least squares is the most common method for estimation of regression functions. It is used for calculation of functions, providing its estimation is linear in parameters or it can be achieved by simple transformation. In fact, we do not know the type of regression function or its parameters β. Therefore, on the basis of empirical data, we must properly capture the character of dependence between dependent variable and independent variables (so choose an appropriate type of regression function) and estimate function parameters. The method determines the Y_j' estimation of the regression function

$$Y_j' = f(x_{1j}, x_{2j}, ..., x_{kj}; b_0, b_1, ..., b_p), \tag{8}$$

where coefficients $b_0, b_1, ..., b_p$ are estimations of unknown parameters $\beta_0, \beta_1, ..., \beta_p$. The difference between empirical and theoretical value of the dependent variable is the random error [1]:

$$e_j = Y_j - Y_j'. \tag{9}$$

If the random errors apply

$$E(e_j) = 0$$

$$\mathrm{D}(e_j) = E(e_j^2) = \sigma^2 \tag{10}$$

$$E(e_{j1}, e_{j2}) = 0 \quad \text{for each } j_1 \neq j_2$$

coefficients $b_0, b_1, ..., b_p$ may be considered as the best estimates of parameters $\beta_0, \beta_1, ..., \beta_p$. (10) shows that random errors have to have a normal distribution with zero mean value (in the case of sufficiently large statistical file) and constant variance (not necessarily, the variance may also vary proportionally). They are independent from *Xi* and should be mutually independent in pairs.

Least-squares condition is that sum of squares of random errors (residual deviations) of dependent variable has to be minimal:

$$F(b_0, b_1, \text{É}\ , b_p) = \sum_{j=1}^{n} (Y_j - Y_j')^2 = \min. \tag{11}$$

Coefficients $b_0, b_1, ..., b_p$ have to suit this requirement. If also a specific type of function (8) is known, it can be inducted into relationship (11) and look for a minimum of the function. The result of the partial derivations of the function $F(b_0, b_1, ..., b_p)$ is then set up to be equal to zero:

$$i = 0, 1, 2, ..., p \tag{12}$$

and the unknown coefficients $b_0, b_1, ..., b_p$ are calculated by solving of a system of $(p + 1)$ equations about $(p + 1)$ unknown quantities. A main disadvantage of the method of least squares is its sensitivity to extreme values and the only one outlier can change a direction of the regression line. Therefore the regression analysis should always start with looking over *X*–*Y* chart [10].

The values of the vector β are used for creating of curves that describe the metamodel. In order to check a suitability of the metamodel for intended purposes, validation of the metamodel (by comparison of metamodel with simulation output data using mathematical statistics) is done. The graphical representation of metamodel's inputs – outputs relationships provides a simple presentation of expected system behavior, often known as the approximate control.

4. Conclusion

Mathematical models are usually used for systems' experimentation. They represent a system in terms of logical and quantitative relationships that can be manipulated and changed in order to find out how the model responds, so as the real system would respond. Many systems are quite difficult for application of analytical solutions on them. There can also occur uncertain conditions with insufficient information and without possibility of solution demarcation. In such a case, the model must be studied by means of simulation. As these models are too complex, their appropriate approximations – called metamodels – are constructed. They relate output simulation data to metamodel's inputs and take into account the random effects occurring in the process. Simulation metamodelling is an appropriate tool for managing and optimization of complex manufacturing systems.

Simulation metamodelling is an appropriate managing and optimizing tool for complex manufacturing systems. The research work [6] was done at the Department of Industrial Engineering of the University of Žilina and it deals with the system analysis of input factors influence on the performance of manufacturing system. This approach uses computer simulation and metamodelling principles, and proposed methods were verified in practical conditions. Other publications focus on metamodelling as a support tool in the frame of Digital factory [4], as a practical approach for a statistical summary of simulation results [3], [5], or as a support tool for designing and testing the control principles in production [12]. Theoretical assumptions and developments were validated on the chosen production system.

The authors' future research is focused on the design and verification of algorithm for approximate production control using simulation metamodelling. A detailed procedure for the metamodel's design will be proposed and evolutionary methods, namely neural networks, will be used in order to improve optimization. A system for automatic generating of metamodel will also be designed and proposed solution will be verified in the framework of the ZIMS research project (Zilina Intelligent Manufacturing System).

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SIMPLIFICATION OF MARKETING SCHEME FOR BUSINESS START-UPS

This paper deals with the topic of marketing planning simplification in order to use it for start-ups in the field of small & medium enterprises. There are 11 main question areas which can be used for logical and empiric marketing approaches. These questions are elaborated on the basis of standard marketing planning methods and approaches from the literature given in references.

Keywords: *marketing, marketing planning, simplification, business start-up, marketing management.*

1. Introduction to the topic

Nowadays development on the markets is strongly focused on new technologies and where they are used. Idea is always the main point but marketing is sometimes left behind. Of course, the product and its parameters are a crucial part of corporate strategy. Without relevant information about market and customers and without funds the idea, no matter how good it is, is doomed to oblivion. Education institutions play an important role in society, should therefore also contribute to the growth of innovation, creative solutions and the increasing competitiveness of the nation [11].

Present markets have also a lot of opportunities for cooperation and partnership, e.g. entrepreneurial and technological incubators, start-up's subvention funds, etc. There are a lot of possibilities how to bring an idea on the market. The problem is often not the lack of opportunities but the lack of information. There are a lot of marketing publications oriented on planning and strategy. These works are often of high quality – their scientific value and the amount of pages are great. Creative people want to work on their ideas only as they are not interested in marketing plans structures and competition analysis methods.

Let us introduce a fictive but realistic example: University is a great environment for new ideas. A few young scientists have made an improvement in technology with high possibility to be successful on the market. Yet the inventors are not interested in marketing. They just want to develop their product. What would they do? They either can offer their idea to the people who have some marketing notion or they can start studying marketing or they just can start using logical and critical thinking and relevant information.

Elaborated marketing structure is a logical construction. It is an approach which enables, by using relevant information and critical stance, to make simple but accurate marketing plans and strategies.

2. Brief theoretical background

According to the marketing management literature authors there are some rules bound to the market success [1, 6, 8, 20]. One of the main current marketing approaches is *customer orientation*. Satisfaction of customers is a never-ending process which depends on various factors. Management must define these factors precisely. The main ones are:

- *Relevant information* about customers which must lead to appropriate segmentation.
- *Segmentation* must be dynamic – this means that the input information must be also actual and relevant. "Know your customer!" – this has to be one of the most important mottos in the company's vision.
- *Quick* and *appropriate* reaction on customers' needs opinions and demands. All this must be recorded and processed by the management information system. To satisfy your customers means that they come back; they will be loyal and spread the loyalty to their social networks.
- *Effective use of company's resources* in terms of customer's satisfaction. In business there must be always profit. Price of the products must be acceptable for the customers and also profitable for the company.

Other approaches are more oriented to single marketing areas. For example, *analysis of competition* is focused on a deep study of company's rivals, on their strengths and weaknesses. The main goal of this method is to have actual information about competitors and to know how to be better or different [2, 5, 10, 14, 19]. *Monitoring of relevant environment* is a method for gathering significant information [12, 13, 14]. Every business exists in specific

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environment. For example, for a software development company the progress in software technologies is crucial. They have to watch this development and try to use the acquired information. There are, of course, a lot of other analysis methods, e.g. product and portfolio analysis, monitoring of marketing communication effectiveness, balanced scorecard, etc.

3. Marketing planning for business start-ups

The following structure is a modification of standard marketing planning structures in terms of simplicity. There are provided 11 questions considering marketing planning. All these questions are logical constructions for basic marketing analysis. This method is intended to be used in small and medium enterprise start-ups, particularly in the field of technological innovations marketing. The application of this method consists in responding to all the questions raised using relevant and significant data.

a) *Know your product!* Obviously it is not a question. It is a must. Deep knowledge of the product is an essential part of marketing process. The main elements of knowledge about product are: technical and other parameters; production process and transformation processes; production costs; possibilities for savings in productions, e.g. with a higher production, etc.; complexity of a product – warranty, packing, servicing, etc.

b) *Who is the customer of this product?* It cannot be said that there is a business without selling. If there is no demand for the product, the product is not relevant for the market. One of the marketing methods used for customer analysis is called *segmentation.* It refers to the arrangement of customers to groups which are homogenous inside and between each other heterogeneous as much as possible. Segmentation is based on the use of segmentation criteria. These are picked in order of their relevance for the case given: economic (e.g. average income), industrial sector (for selecting only the companies from the relevant sector), technology usage level (for some companies technology is more crucial), etc. The primary segment or segments should be specific as much as possible – in b2b there should be specific companies.

c) *How, where and when will the customers know about your product?* The whole industrial branch nowadays is marketing communication. Mass media are the most expensive ones. Traditional communication channels are overloaded with communication. If I know my primary segment, I can be precise and specific and I can choose media and techniques which are "for optimal price". In some cases it could be just e-mail or event presentation. Content of communication should be adapted for the taste, style and tendencies of target group (primary segment). For example, there is a huge difference between marketing communications of products of the same brand to various segments: cameras for mass consumer segment are advertised on TV, radio and newspapers; cameras for professionals in annual expositions, professional magazines and webzines, etc. It is also necessary to know the sum which could be used for marketing communication. Simple decisions on marketing communication can be performed through answering the following questions: Who do I want to address?; How much money do I have for it?; What do I want to say?; Which techniques will be used?; Which media do I chose?; What will be the time and frequency framework?; What can I handle and what do I need any help with?; What kind of effects can be expected?

d) *How will your product reach the customers?* We are speaking about distribution, which should have exact parameters. We also speak about the place where the customer meets the product or consumes it (the point of purchase, web pages, etc). In order to ensure the customer's satisfaction it is necessary to reach comfort, security and speed of product delivery. The company's goal should be the same in order to gain payment and also customer's satisfaction.

e) *How much will your product cost?* Price of the product can be simple set by responding the following question: How much do you have to earn to have a profit? There is crucial to know the production costs. It is not only the production, it could also be energies, rent, licenses, taxes, etc. If there is a profit, it is good to know how to use it (expand, invest, etc). There should be a system of discounts (quantity, closeness of delivery, promptness of payment, the way of payment, reciprocity – barter, etc). It is also good to know the prices of competitors. So, the final price could be set by counting all costs for production with the projected profit.

f) *Who are your competitors, what are they good at and why is that so (and vice versa)?* We are talking about the substitution – your competition is everything that can replace your product by the customer. So, competition is not only homogenous – the same or similar products as yours – but also substitution – different products assigned for the same group of consumers. It is necessary to have a deep interest in competition. We can learn from competition. We can find their strong and weak sites and use it in our strategies.

g) *Who can be your partner?* Currently, partnership and cooperation are considered to be business strategies. It is always possible to use some start-up funding mechanism, incubation, join the cluster or network. These opportunities could raise your competitiveness. In business partnership is always important one question: What benefits can I get and what do I have to offer?

h) *What else opportunities, threats or limitations exist on the market where you want to realize yourself?* If we are talking about business we must also consider impacts from wider environment. Mostly they are: legislature (civil law, business law, taxes, charges, judicial system, etc); macro-economic stage of market (average salaries, income per capita, willingness to investments, willingness to buy, GDP, GNP, etc); technology, R&D (availability, access, stage, prices, etc); cultural and social issues; natural environment impacts, etc.

i) *What are your business goals?* Your goals should reflect the answers to the previous questions. You can set your goals properly after you have relevant information about market. The goals should be set within the S.M.A.R.T. method. This method tells us that every goal must be specific, measurable, attainable, relevant and time-bounded[1)].

[1)] More information to the S.M.A.R.T. method here: http://www.projectsmart.co.uk/smart-goals.html; http://en.wikipedia.org/wiki/SMART_criteria

j) *What are your plans and strategies for reaching your goals?* In terms of simplification here you can just work out your approaches for reaching your goals. There are a lot of methods in the field of strategic management and marketing literature you can use. To do it simple follow these rules:
   - Logical structure. Allocate main processes and connect them in order to achieve your goals.
   - Time limitations. Every process should be performed in delimitated time.
   - Setting of competencies.
   - Setting of budget or expenses.
   - Use of visualization – e.g. Gantt charts, etc.

k) *Control!* We have started with the command and finish also with another one. When all plans are made you are ready to launch them on the market. When you have set your plans and strategies into logical processes you will be able to control them. Just mark the main points or parts of your plan and control if the reality responds to the project. If there are any differences you can learn about the reasons and make corrections.

4. Conclusion

It is always good to know the successful marketing conceptions. All the questions are elaborated from the main planning approaches and case studies of successful start-ups. To use these questions for planning of marketing process it is necessary to be critical – critical in the way of approach. Answers of single questions should be precise and accurate. There should be used arguments and facts. All data used for answering must be relevant and actual. Simplification doesn't mean easiness. Questions and approach are simple for understanding – for performing it is a quite hard work. There are a few recommendations for improving marketing planning:
- Consult with people who are relevant or have relevant information and are accessible.
- Be critical to your projects.
- Use information and criticism to your advantage.
- Be interested in the market about all relevant events and information.
- Watch the competitors.
- Listen to your customers and potential customers.

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SUPERVISORS' ASSESSMENT ACCORDING TO BOST METHOD IN A CHOSEN POLISH COMPANY

The main subject of the research presented in this paper is assessment of Polish supervisors with use of 4E+1P principle, 12 golden rules and Toyota's principles. This is a part of research conducted within the confines of BOST method, based on the rules of Toyota's system. This test method can be successfully used both in production and service institutions. There are two versions of the survey questionnaire: for supervisors and staff. The questionnaire includes also: the most important areas of improvement, visual control of factors, elements of the manufacturing process, competitive products, assessment of the supervisors and manufacturing processes. The results of research are presented as tables and bar charts.

Keywords: *BOST method, 4E+1P principle, 12 golden rules, Toyota's principles, supervisor*

1. Introduction

The BOST method presented in papers [1, 2] was used for carrying out the research. This test method, based on the Toyota's production system can be successfully used both in production and service institutions.

There are two versions of the survey questionnaire in this study: for supervisors and staff. The questionnaire includes: the most important areas of improvement, visual control of factors, elements of the manufacturing process, assessment of the supervisors, competitive products and manufacturing processes. The final part of the survey includes the respondent's birth certificate and determines the nature of the business. With use of the BOST method a human resources company can be characterized. This method includes also a SERVQUAL method questionnaire [3] which measures quality of service.

2. Description of research problem

Development of the problem was based on three issues relating to:

1. Assessment according to 4E+1P principles, based on 5 features: 1E – Is full of enthusiasm all day long, 2E – Is able to encourage others to take actions, 3E – Makes decisions fast, 4E – Knows how to implement decisions, 1P – Cares for the success by co-workers.
2. Assessment according to golden rules based on 12 features: KA – Sets good example, KB – Communicates about goals of actions, KC – Informs about news in the company, KD – Asks staffs about advice, KE – Gives support during performance of tasks, KF – Directs and requires, KG – Allows to improve work independently, KH – Prizes for good work, KI – Thanks openly, KK – Criticizes in discreet manner, KL – Forgives and encourages to achievement of good results, KN – Is open to ideas by the staff.
3. Toyota's principles that is what leaders do?, based on 8 features: KP – Improves work in his team, KR – Cares if the team lives by company's vision, KS – Influences with energy and positive attitude, KT – Is open, KV – Is confident while decision-making, KW – Cares if his questions are followed by actions, KU – His behavior inspires for learning, KZ – Is success-driven.

The 4E+1P principles [4] are used for assessment of the candidates during interviews for managerial positions. The twelve golden rules [5] contain comprehensive characteristics of a person and can be successfully used during investigations. Toyota has developed leader traits (8ZT) which can also allow for revealing a number of supervisor traits [6].

The workers have to agree or disagree with all statements divided in these 3 groups. In this way it was possible to indicate main features of the supervisor according to the interviewed workers.

3. Characteristics of research company

Company X started its activities in 1982. Manufacturing plant with technical facilities is located in Sosnowiec.

From the beginning, the company is associated with the automotive industry. In this regard, the company performs technical services for the design, execution and assembly. It designs and manufactures technical equipment of production lines, mainly: pen-

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dants to transport the body of a car, car parts (doors, fuel tanks, seats, etc.), storage pallets, as well as trucks to transport the sequence of components from storage to the cost assembly/production. In addition, it manufactures auxiliary equipment used in mass and small series production for the automotive and other industries.

The company's portfolio also includes equipment and tools for hot extrusion of aluminum profiles. These include the device for the separation of the forming dies, conveyor production lines, both predefined and generated waste products (roller, apron, chain conveyors). In cooperation with foreign companies, the company X produces covers and roofs for recreational and commercial sports halls, which creates a support structure. The company X designs and produces construction with very complex shapes and narrow tolerances.

4. Structure of the interviewed employees

Among the employees of the company X the survey BOST, on the basis of which immaterial stores occurring in the enterprise were evaluated, was conducted. The study involved 25 workers selected at random: 5 white-collar workers (doing office work) and 20 blue-collar workers (doing production work).

The human resources of the company, which are presented in Table 1, are one of the criteria of the research. These resources were divided by gender, education, age, work experience, place of work.

Percentage fraction of the structure of workers in a research company according to: a) gender, b) education, c) age, d) work experience, e) place of work. Tab. 1

a)

Gender	Value [%]
Man	96
Woman	4

b)

Education	Value [%]
Elementary	4
Vocational	8
Secondary	68
Higher	20

c)

Age	Value [%]
below 30 years	16
31 – 40 years	60
41 – 50 years	12
51 – 55 years	4
56 – 60 years	4
61 – 65 years	4

d)

Work experience	Value [%]
below 5 years	16
6 – 10 years	28
11 – 15 years	20
16 – 20 years	12
21 – 25 years	8
26 – 30 years	4
31 – 35 years	8
36 – 40 years	4

e)

Place of work	Value [%]
Second	48
Third	32
Fourth	20

From the conducted survey in terms of human resources it results that in the company X men constitute a larger number of employees than women. Men constitute 96% of the employees, while women are only 4%. It is obvious that the automotive industry is a typical industry for men.

The company is dominated by workers with secondary education who constitute 68%. The second group consists of people with higher education who include 20%. It is possible to notice that the company hires mainly educated people (88% employees with at least secondary education).

Most numerous age group constitutes 60% of employees in the company, these are persons aged 31 – 40 years, 16% were younger than 30 years. It means that the company hires mainly young people (76% below 40 years).

Analyzing the work experience it can be seen that most people has been working in the company for 6 – 10 years (28%). It is moderate work experience allowing for accustoming to activities and becoming intimate with the entire crew. 20% of people are about slightly bigger internship from 11 – 15 years which also supports better atmosphere at the work. People, who started their work in the company less than 5 years ago, represent 16% of all employees. Concluding, 64% of the workers started their work in the company less than 15 years ago. It means that they are already experienced but because of their young age they are more open for new technology.

For 48% of employees the research company is the second place of work. It should be emphasized that for none of the employees the company X is their first place of work. It means that all employees worked before somewhere else and they already have some work experience. The number of jobs (place of work) is another element of the investigation in the survey. For 48% of employees this workplace is their second job. It is important that none of the workers indicated their first place of work. It means that the research

company is not the first place of work for employees; they already gained experience somewhere else.

5. Supervisors' assessment according to different tests

Results of characteristics of supervisors based on the 4E+1P principles are presented in Table 2. Their graphic interpretation is presented in Fig. 1.

Assessment's structure according to the 4E+1P principles Tab. 2

Result	Denotation of principle [%]				
	1E	2E	3E	4E	1P
YES	40	64	64	92	48
NO	60	36	36	8	52

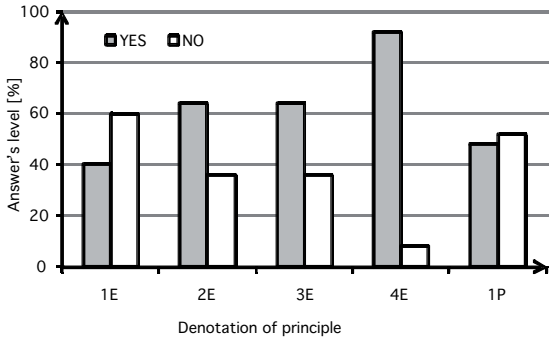

Fig. 1 Supervisor's assessment characteristics based on the 4E+1P principles – rating structure

According to the 4E+P principles an ability of 4F – To know how to implement decision is the most important feature of the supervisor amount respondents (96% of YES). Features: 2E – To be able to encourage others to take actions, 3E – To make decisions fast are also highly assessed (64% of YES). Unfortunately according to the respondents the supervisor 1E – in not full of enthusiasm all day long (60% of NO). During the assessment of superiors according to the 4E+P principles a vast number of employees of the company X concluded that the most important feature, representing 92% of the possession of the superior, is 4E – To know how to implement decisions. 2E – To be able to encourage others to take actions and 3E – To make decisions fast are also important – 64% of respondents think in this way. 60% of respondents responded "NO", taking into account whether the supervisor 1E – Is full of enthusiasm all day long.

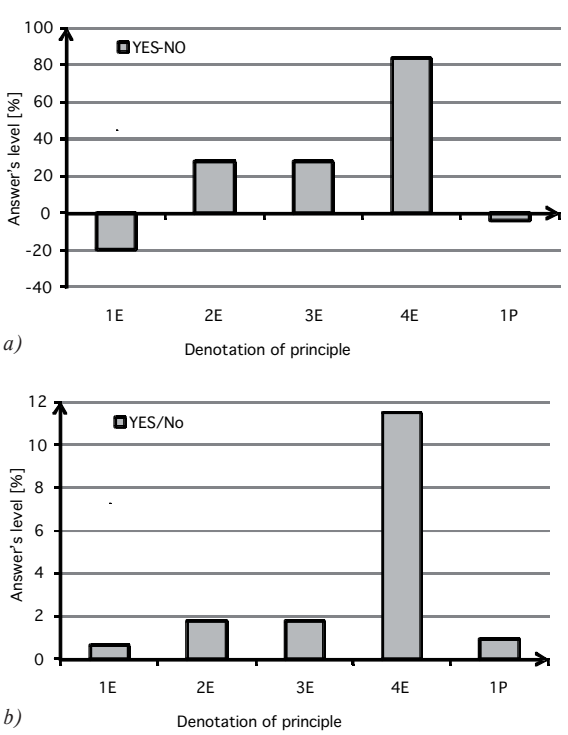

Fig. 2 Supervisor's assessment characteristics based on the 4E+ 1P principles:
a) difference YES-NO, b) quotient YES/NO.

To visualize the difference between YES and NO answers, the difference and quotient of these answers were calculated. The results in case of the 4E+1P principles are shown in Fig. 2.

In 3 cases: 2E – Is able to encourage others to take actions, 3E – Makes decisions fast, 4E – Knows how to implement decisions, the difference YES-NO is above 0, what means that in these cases the employees often answered yes, especially in case of 4E. If it comes to the quotient of YES/NO, it is possible to be seen that in the case of element 4E – Knows how to implement decisions, respondents answered YES almost 12 times more often than NO.

Assessment structure according to the 12 golden rules Tab. 3

Result	Denotation of principle [%]											
	KA	KB	KC	KD	KE	KF	KG	KH	KI	KK	KL	KN
YES	80	88	64	36	88	96	68	44	36	72	72	80
NO	20	12	36	64	12	4	32	56	64	28	28	20

Results of characteristics of supervisors based on the 12 golden rules are presented in Table 3. Their graphic interpretation is presented in Fig. 3.

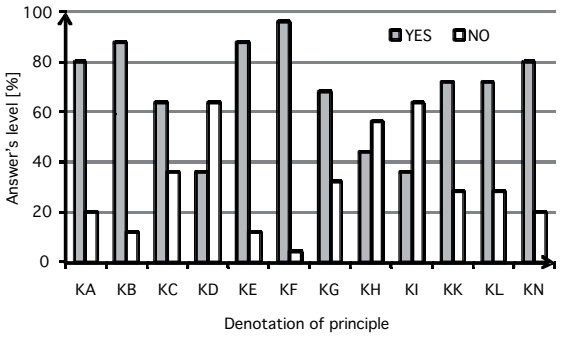

Fig. 3 Supervisor's assessment characteristics based on the 12 golden rules – rating structure

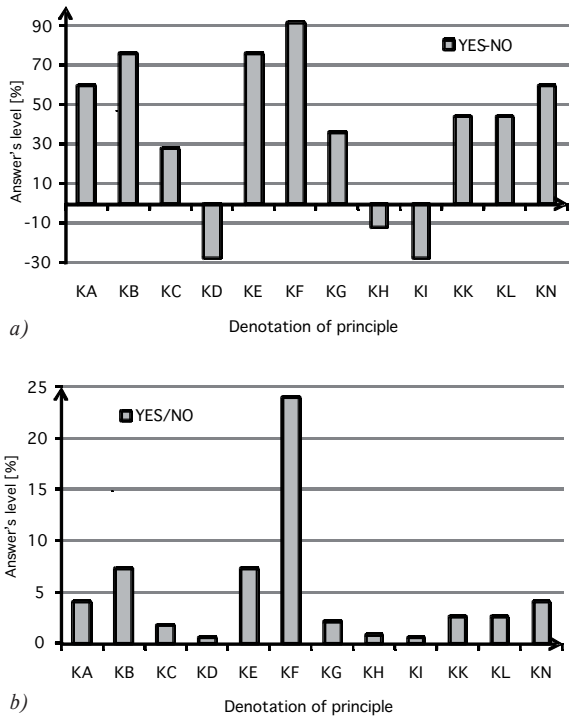

Fig. 4 Supervisor's assessment characteristics based on the 12 golden rules:
a) difference YES-NO, b) quotient YES/NO

An ability of KF – Directing and requiring of employees is a top-rated feature of superior among the respondents, which amounted to 96% of YES. Features: KB – To communicate about goals of actions and KE – To give support during performance of tasks were also very high assessed (88% of YES). Unfortunately according to the interviewed the supervisor KD – Does not Ask staffs about advice, KI – Does not thank openly (64% of NO).

The difference and quotient of the answers in case of the 12 golden rules are shown in Fig. 4.

Only in 3 cases: KD – Asks staffs about advice, KH – Prizes for good work and KI Thanks openly the difference YES-NO was below 0. It means that only in these 3 cases the workers answered NO more often than YES. If it comes to the quotient of YES/NO, it is possible to be seen that in the case of element KF – Directs and requires, respondents answered YES 24 almost times more often than NO.

Results of characteristics of supervisors based on the Toyota's principles are presented in Table 4. Their graphic interpretation is presented in Fig. 5.

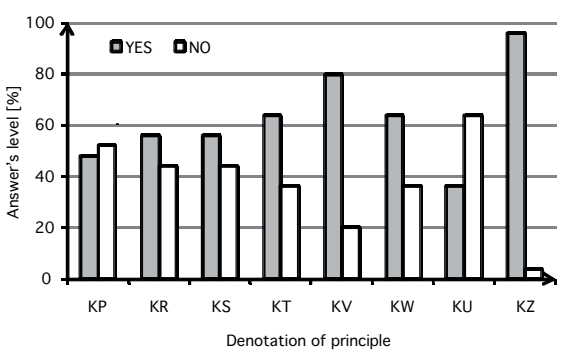

Fig. 5 Supervisor's assessment characteristics based on the Toyota's principles – rating structure

The feature: KZ – To be success-driven received the highest score – 96% of YES. KV – To be confident while decision-making also was assessed highly – 80% of respondents said YES.

Respondents stated at the same time that KU – the behavior of their supervisor does not inspire for learning (64% of NO).

The difference and quotient of the answers in case of the Toyota's principles are shown in Fig. 6.

Assessment structure according to the Toyota's principle Tab. 4

Result	Denotation of principle [%]							
	KP	KR	KS	KT	KV	KW	KU	KZ
YES	48	56	56	64	80	64	36	96
NO	52	44	44	36	20	36	64	4

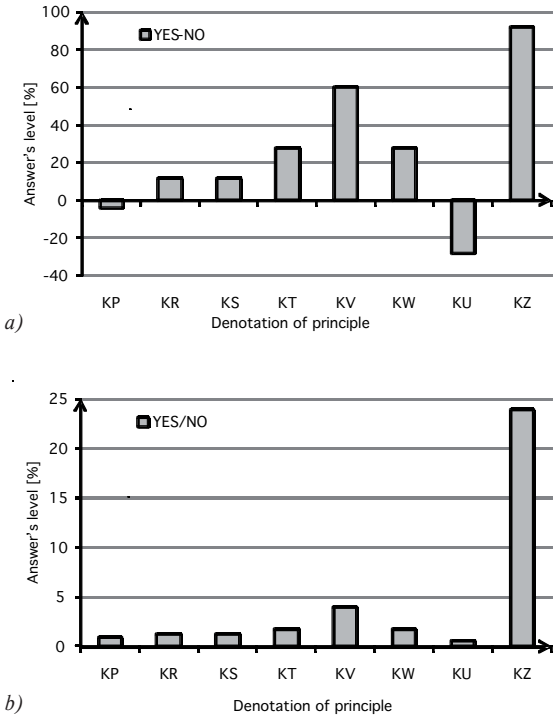

Fig. 6 Supervisor's assessment characteristics based on the Toyota's principles:
a) difference YES-NO, b) quotient YES/NO.

Only in 2 cases: KP – Improves work in his team and KU – His behavior inspires for learning the difference YES-NO was below 0. It means that only in these 2 cases the workers answered NO more often than YES. If it comes to the quotient of YES/NO, in the case of element KZ – Is success-driven respondents answered YES 24 almost times more often than NO.

6. Conclusion

Suitability of the 4E+1P, the 12 golden rules and the 8 Toyota's principles for assessment of leadership traits was determined for a supervisor from one of the Polish companies. Quantitative comparison of acceptance level for the traits contained in the principles was made. Impact of personal traits of the employees on the acceptance of manager traits was also determined.

Multi-aspect analysis of the results points to the suitability of the 4E+1P principles, the 12 golden rules, the Toyota's principles for determination of leadership traits in supervisors. The obtained results are characteristic of the manager, which emphasizes sensitivity of the adopted research methodology to a variety of factors.

The employees of the research company described in BOST surveys their supervisor, indicating his main features. They claimed that he:
- 4E – Knows how to implement decisions,
- KB – Communicates about goals of actions,
- KE – Gives support during performance of tasks,
- KF – Directs and requires,
- KV – Is confident while decision-making,
- KZ – Is success-driven,

but unfortunately the same time he:
- 1E – Is not full of enthusiasm all day long,
- KD – Does not ask staffs about advice,
- KI – Does not thank openly,
- KU – His behavior does not inspire for learning.

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THE WAR ON TERROR DISCOURSE: THE CASE OF THE SECOND GULF WAR

Abstract. This paper deals with the notion of discourse as manifested in political text and talk. The theoretical part elaborates the concept of political discourse with special focus on political speeches. Particular attention is also placed on Critical Discourse Analysis, which provides theoretical framework for the study. The subject of the analysis is the discourse of former British Prime Minister Tony Blair during the campaign for the invasion of Iraq in March 2003 and during the initial stages of the military operation itself.

Keywords: *discourse, Critical Discourse Analysis, political discourse, The War on Terror.*

1. Introduction

The events of 9/11 had tremendous political consequences for the world of international affairs. After terrorist attacks on the United States, there followed a series of overseas military operations mainly in the Middle East and also in Afghanistan. These operations were designed to fight the declared "War on Terror" and were executed by the United States and its allies. Great Britain was also a member of the US – led coalition – as a principal ally of the USA.

After 9/11 attacks, there also came into existence a new type of rhetoric, which was aimed at justification of these military actions. If leaders wanted to justify their actions and decisions in the public, they had to communicate their arguments in a clear, coherent and persuasive manner.

In this paper, I will present an analysis of selected fragments of discourse taken from the speeches by former British Prime Minister Tony Blair. The fragments from his speeches present examples of how discourse may be used and structured for purposes of persuasion. The article also presents theoretical framework for Critical Discourse Analysis.

2. Political Discourse

Chilton [1, p. 4] claims that "language and politics are intimately linked at a fundamental level."

Horvath [2, p. 45] also considers language as being essential in political affairs and comments on the role of language in politics: "in this process, language plays a crucial role, for every political action is prepared, accompanied, influenced and played by language."

Indeed, language plays a vital role in the construction of ideological positions. No matter how politics is defined, it also involves a linguistic, discursive and communicative dimension. Politicians are aware of the potential of language use and therefore they attach great importance to communicative events.

One of the main aims of the analysis of political discourse is to specify the ways in which particular choice of language is manipulated for specific political goals. Examples of political discourse can be analyzed almost on all levels of linguistics from lexis to pragmatics. Political discourse may contain covert as well as overt linguistic tools that serve for shaping of public opinion. On the syntactic level, for example, reversal of the word order can be used for stressing certain information.

Chilton and Schaffner [3, p. 211] assume that the "task of political discourse is to relate the fine grain of linguistic behaviour to what we understand by "politics" or "political behaviour." Within political discourse, Van Dijk [4, p. 176] distinguishes between the following genres: "parliamentary debates, laws, propaganda, slogans, peace negotiations, international treaties." In addition to the above mentioned genres, political speeches also present an essential component of political discourse. Within political discourse, speeches given by politicians are a particularly important genre.

As a genre of political discourse, political speech, according to Dedaic [5, p. 700] represents

"relatively autonomous discourse produced orally by a politician in front of an audience, the purpose of which is primarily

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persuasion rather than information or entertainment. [...] The orator is speaking face to face with his or her audience and deals with a controversial issue. Generally, the purpose of any political speech is to convince the audience that his or her standpoints are correct and plausible."

Dedaic [5, p. 700] continues to claim that political speeches can be classified either by the occasion (commemorative, inaugural, etc.), by the speaker (political candidate, national leader) and by audience (TV, local national, international).

Especially in the Western countries, speeches of the prime minister or the president (these include, e.g. inaugural addresses, war rhetoric, farewell addresses, state of the nation addresses, etc.) are prominent social and political events and preferred objects of linguistic analyses – it is because these speeches produce linguistic as well as sociopolitical ties with audiences.

As far as persuasion in political discourse is concerned, it is generally viewed as the primary aim of majority speeches to the public. In Dedaic's view [5, p. 702] "persuasion is an attempt to change human behavior or to strengthen convictions or attitudes through communication. (...) The orator employs argument and rhetorical devices, such as evidence, lines of reasoning, and appeals that support the orator's aims." In the case of the conflict in Iraq, the argument related to weapons of mass destruction was frequently employed, repeatedly stressed by Western leaders and it played an essential role in decisions about military involvement.

3. Critical Discourse Analysis

The theoretical framework for this study is situated within Critical Discourse Analysis. The roots of CDA go back to the 1970's. The main stimulus for the emergence of "Critical Linguistics" was provided by publication of the book entitled *Language and Control* [6]. As the title implies, the book was primarily concerned with the relationship between language and power. Fowler [7, p. 3] claims that the authors provided an analysis whose aim was to "get at the ideology coded implicitly behind the overt propositions, to examine it particularly in the context of social formations."

Critical Discourse Analysis emerged from the writings generally associated with Critical Linguistics and also with Systemic Functional Linguistics. Critical linguistics and Critical Discourse Analysis are seen as useful tools for analyzing political speeches, gender inequalities, etc.

Hopkinson [8, p. 32] suggests that this theoretical framework for the study of discourse is also used when studying "manipulative media discourse, and the strategies it uses to achieve its aims."

According to Schaffner and Wenden [9, p. xviii], the main goal of Critical Discourse Analysis is to "analyse language and the functioning of language in its social context." The adjective "critical" is not used in a negative sense. Young and Fitzgerald [10, p. 8] claim that this term is used "to describe a way of looking at language *reflectively*, that is, asking why a speaker/writer has chosen certain words and structures, and not others." CDA sees context of language use as an essential component for any analysis. Furthermore, CDA encompasses and makes use of rhetoric, sociolinguistics and also pragmatics.

Van Dijk [4, p. 85] views CDA as "a type of discourse analytical research that primarily studies the way social power abuse, dominance and inequality are enacted, reproduced and resisted by text and talk in the social and political context."

Over the last two decades, this approach has become very influential in the study of various discourses. CDA primarily focuses on the relationship between language and power, as well as on "the way discourse structures enact, confirm, legitimate, reproduce or challenge relations of power and dominance in society." [4, p. 86]

According to Caldas – Coulthard [11, p. xi], discourse is considered an important aspect of "power and control and Critical Discourse Analysts [...] feel that it is indeed part of their professional role to investigate, reveal and clarify how power and discriminatory value are inscribed in and mediated through the linguistic system."

CDA is also specifically interested with how one group controls or influences another group through the form of content of text and talk.

Fairclough points out that CDA is "based on the assumption that "language is an irreducible part of social life, dialectically interconnected with other elements of social life." [12, p. 2]

In general, it might be said that CDA views language as a form of social practice and attempts to make people aware of the influences of language and social structure of which they are usually unaware.

4. Analysis of Tony Blair's Discourse on Iraq

4.1. General features of Tony Blair's rhetoric

In this part of the paper, different recognitions and shifts of perception of "evil" in Tony Blair's view will be presented.

In general, the main feature that can be attributed to Tony Blair's rhetoric is that of "struggle between good and evil." In this bipolar division, Blair is frequently typified as an agent of "good" involved in the struggle against "evil." [13, p. 150]

In the following, changes in Blair's perception of the notion of evil throughout different periods of time will be discussed, drawing mainly on the work by Charteris – Black [13, p. 150].

Before 9/11, it was mainly social injustice and its roots that Blair considered "evil." This is manifested in his speech from September 2000:

(1) "Crime, anti-social behaviour, racial intolerance, drug abuse, destroy families and communities. They destroy the very respect for others on

which society is founded. They blight the life chances of thousands of young people and the quality of life of millions more. Fail to confront this evil and we will never build a Britain where everyone can succeed." (Tony Blair, September 26, 2000) [14, par. 49 – 50]

The following year, Blair changed the subject of the embodiment of evil – at that time, the focus was placed on terrorism. He stated:

(2) "This mass terrorism is the new evil in our world today. It is perpetrated by fanatics who are utterly indifferent to the sanctity of human life and we, the democracies of this world, are going to have to come together to fight it together and eradicate this evil completely from our world." (Tony Blair, September 11, 2001) [15, par. 2]

In 2003, during the campaign for the military operation in Iraq, it was Saddam Hussein who was perceived as "evil." Tony Blair's proclamation is as follows:

(3) "Looking back over 12 years, we have been victims of our own desire to placate the implacable, to persuade towards reason the utterly unreasonable, to hope that there was some genuine intent to do good in a regime whose mind is in fact evil." (Tony Blair, March 18, 2003) [16, par. 9]

4.2. Tony Blair's Discourse during the campaign for the Iraq War in 2003

The focus of this part of the paper will be placed on Tony Blair's rhetoric during the campaign for the invasion of Iraq and during the initial stages of invasion in March 2003.

For the purpose of the analysis, short fragments of his speeches from this period were selected. The aim of this selection is to demonstrate some basic tools of Critical Discourse Analysis, namely presupposition and the usage of pronouns.

Ponton [17, pp. 11–16] considers presupposition and usage of pronouns as basic tools for Critical Discourse Analysis. Presuppostion is defined by Yule [18, p. 25] as "something the initiator of communication assumes to be the case prior to making utterances."

In the following excerpt, Tony Blair, without any justification, claims that Saddam Hussein's possession of weapons of mass destruction is implicit:

(4) "Our aim is to disarm Saddam of his weapons of mass destruction." [19, par. 14]

Such statements, although unjustified, may be perceived as veritable in the public. However, Ponton suggests that "in the case of Iraq, an invasion was necessary to demonstrate that Blair's presupposition was false." [17, p. 14] Nonetheless, it might be stated that the presupposition employed by Tony Blair achieved its primary function associated with legitimization of military action.

As far as the usage of pronouns in discourse is concerned, Fairclough [20, p. 106] distinguishes between the so called inclusive and exclusive *we*. He provides the following examples taken from a *Daily Mail* editorial: "We cannot let our troops lose their edge below decks while Argentine diplomats play blind man's bluff round the corridors of the United Nations." Fairclough [ibid.] further argues that by employing "inclusive" *we*, "the newspaper is speaking on behalf of itself, its readers, and indeed all British citizens." On the other hand, "exclusive" *we* "refers to the writer (or speaker) plus one or more others, but does not include the addressee (s)."

Similar use of *we* can be found in Tony Blair's discourse on Iraq:

(5) (...) "Once again he refused. The choice the international community then faced was to disarm Saddam by force and oust his regime or to back down and to leave Saddam hugely strengthened to attack or intimidate his neighbours and to pass on these weapons to terrorist groups. I believe that history will judge that we made the right choice." (Tony Blair, March 30, 2003) quoted in [17, p. 13]

In this fragment, Tony Blair directly implies that "the international community" was facing a choice. Towards the end of his proclamation, he states that "we made the right choice." However, as aptly noted by Ponton [17, p. 13], "the choice to disarm Saddam and oust his regime was not taken by the international community at all, but by Britain and the United States." These two countries did not take into account opinions of other important world powers. Ponton [ibid.] goes on to argue about the logic behind Blair's usage of pronoun by claiming that "Blair has used rhetorical 'sleight of hand' to smooth over conflicting opinions within the international coalition; and, by constructing a rhetorical front of international unity behind his favoured policy, make the military option more persuasive to his current listeners."

5. Conclusion

This paper has presented a brief overview of the interplay between language and politics. Starting with the concept of political discourse as such, continuing with description of the main features of political speeches, and introducing the framework of Critical Discourse Analysis, the paper has also presented an attempt how to explore discursive properties of political speeches.

Bloor and Bloor [21, p. 7] argue that "the linguistic analysis of texts has many practical applications above and beyond knowledge about language for its own sake. It can help us to find out why some texts are more effective than other texts at communication or persuasion." The fragments from the speeches of former British Prime Minister Tony Blair's speeches have illustrated how leaders may communicate their political aims and ideas.

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Wiktor Wcislik *

EFFECT OF THE STRESS STATE TRIAXIALITY ON THE VALUE OF LIMIT STRAIN OF MICRO-VOID DEVELOPMENT IN S235JR STEEL – NUMERICAL ANALYSIS

Abstract. This paper deals with the numerical analysis of plastic deformation and damage development in S235JR steel in complex stress states. The material Gurson Tvergaard Needleman (GTN) model was applied. The analysis was performed for notched bars subjected to tension. An attempt was made to investigate the effect of stress triaxiality on the value of critical strain of voids growth in the GTN model.

Keywords: *ductile fracture, porous metal plasticity, GTN model, numerical analysis.*

1. Introduction

Computing load carrying capacity of steel components of civil engineering structures at the design stage is a well-defined, relatively well-known process. It is far more difficult to make an analysis of existing structures operating under structural failure conditions (overload, damages to load bearing elements). In such a case, it is required to account for plastic reserve of the material load bearing and to apply the principles of fracture mechanics.

It is essential to employ a model of the material plastic flow. In the literature on the subject, one can find many solutions [1, 2], yet their practical applications, especially to complex stress states, could be sometimes restricted.

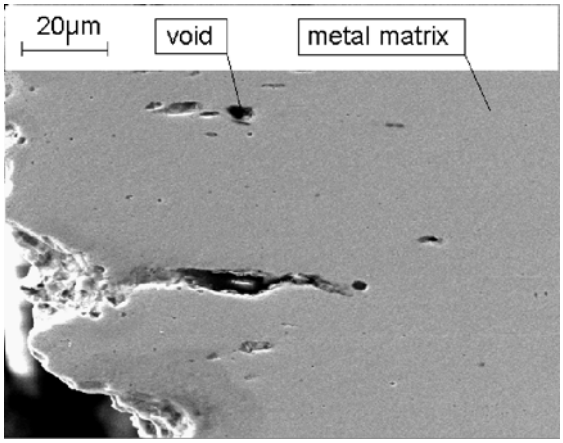

Fig. 1 Microstructure of investigated steel

Models of porous bodies offer a lot more possibilities [3, 4]. They describe fracture process by means of growth and coalescence of voids that are initiated on the boundary of the metallic matrix and the second phase particles (mainly sulphur and manganese compounds) – Fig. 1.

One of the solutions in the field is GTN model of the material. In order to obtain most reliable results, it is of key importance that the values of strains accompanying micro-void development are determined. According to many authors, the process of micro-void growth depends primarily on the degree of stress state triaxiality. That implies a similar pattern of changes will be demonstrated by strain values at the instant of rapid micro-void development and failure. The present paper aims at determining values of effective strains that accompany micro-void growth and the component failure as a function of a degree of stress state triaxiality.

2. GTN model

The description of the process of plastic fracture in metal alloys with technical applications is frequently presented using the model developed by Gurson [5], which was later modified by Tvergaard and Needelman. The model makes it possible to account both for the law of macroscopic plastic flow and the growth of micro-voids nucleating on inclusions and precipitations. The model application to the analysis of fracture process has been extensively investigated.

Void volume fraction is a basic parameter of the model. That is defined, in accordance with the formula below, as a ratio of a current micro-void volume to the sample volume:

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$$f = \frac{V_V}{V} \tag{1}$$

where: V_v – current void volume fraction, V – sample volume

Strains and stresses are determined at macroscopic level. Yield criterion is expressed as follows:

$$\Phi = \frac{\sigma_{eq}^2}{\sigma_M^2} + 2q_1 f \cosh\frac{3q_2\sigma_m}{2\sigma_M} - 1 - q_3 f^2 = 0 \tag{2}$$

where: Φ – non-dilatational strain energy, σ_{eq} – reduced stress in accordance with Huber Mises Hencky criterion, σ_M – yield point, σ_m – mean stresses (the arithmetic mean of major stresses), q_1, q_2, q_3 – Tvergaard coefficients, f – current volume fraction of voids expressed by the following dependence:

$$f = \begin{cases} f & for\ f \le f_c \\ f_c + \dfrac{\overline{f_F} - f_c}{f_F - f_c}(f - f_c) & for\ f_c < f < f_F \\ \overline{f_F} & for\ f \ge f_F \end{cases} \tag{3}$$

where: f_c – critical void volume fraction corresponding to the lowered strength of the material, f_F – void volume fraction corresponding to the loss of the material load-carrying capacity, $\overline{f_F} = [q_1 + (q_1^2 - q_3)^{0,5}]/q_3$

The process of void growth is closely related to the stress state, more precisely to the triaxiality degree defined as σ_m/σ_{eq}, where σ_m – mean stress value, σ_{eq} – equivalent tension, determined in accordance with the respective formulas:

$$\sigma_m = \frac{\sigma_{11} + \sigma_{22} + \sigma_{33}}{3} \tag{4}$$

$$\sigma_{eq} = \frac{1}{\sqrt{2}}\left[(\sigma_1 - \sigma_2)^2 + (\sigma_2 - \sigma_3)^2 + (\sigma_3 - \sigma_1)^2\right]^{1/2} \tag{5}$$

3. Specimen types and investigation methodology

In order to check how correct the computational results are and whether the GTN model parameters were selected properly, specimens with a ring notch underwent tension testing (Fig. 2a).

The specimens used in investigations were 12 mm in diameter, with the notch bottom radius R = 1, 4 and 10 mm. Initial values of degree of stress state triaxiality in the axis of each specimen were equal to 1.943, 1.026, 0.670, respectively.

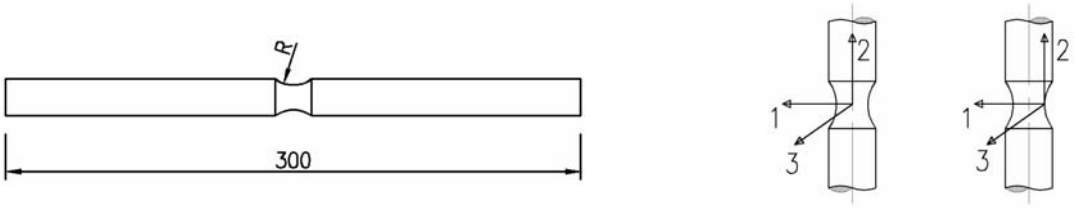
Numerical simulation of the tension tests performed on components with a notch was conducted. Computations were carried with ABAQUS Version 6.7 software. Due to the transverse symmetry of the specimens used (where the notch bottom cross section surface was the symmetry surface) only one half of the specimen was modeled. The presence of the longitudinal axis of symmetry allowed for the use of axisymmetric model and simplifying the calculation. Basic mesh size was 1 mm, but the mesh density around the notch was about three times higher. The model assumed blocked translation of the transverse symmetry surface. Loading was carried out at a controlled displacement of the end of the specimen. Standard axi-symmetrical CAX4R elements and the material GTN model were applied.

Computation results produced curves illustrating tension of components with a notch, graphs showing void volume fraction and values of strains accompanying the nucleation and rapid growth of micro-damages (in the specimen axis and on the notch surface). Notation convention for individual components of strains is presented in Fig. 2b that shows coordinate systems for measurement in the specimen axis (on the left) and on the notch surface (right).

4. Analysis of results

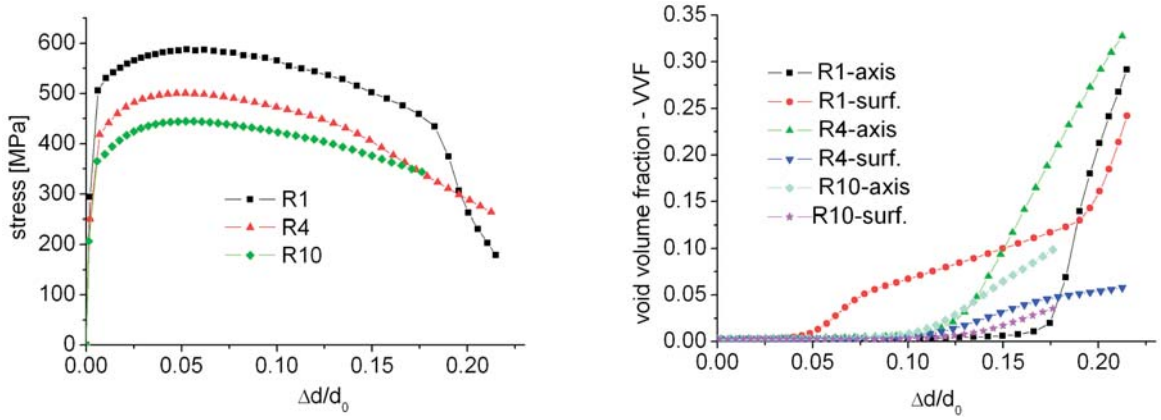
The results of numerical computations for specimens with a notch are presented below. In all graphs, strain defined as the quotient of the specimen neck in the notch bottom by the initial diameter in this cross section, is an independent variable and a reference parameter.

The analysis of the tension curve for specimens with 1 mm notch (Fig. 3a) makes it possible to state that the stress maximum is reached when the strain d/d_0 (ratio of current diameter in the notch cross section to the initial diameter) equals 0.055. Fig. 3b shows that decreasing stress values are accompanied by a rapid increase in void volume fraction on the surface of the notch bottom, whereas the data in work [3] indicate void intensive development in the specimen axis. Rapid void growth was observed for the strain of 0.037. The rate of micro-damage development is relatively constant until the strain reaches approx. 0.19, after which the speed



a) *b)*

Fig. 2 Specimens used in investigations (a) and notation convention for individual components of strains (b)



a) *b)*

Fig. 3 Numerically determined tension curves (a) and void volume fraction in the axis and on the notch surface of specimens (b)

of the process increases rapidly again. At the instant of failure, the void volume fraction in the cross section amounted to 30%, which shows good congruence with the data in [3].

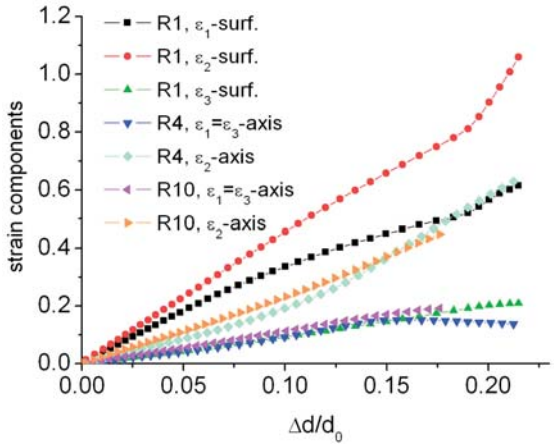


Fig. 4 Strain components in the areas of the highest void growth intensity

Fig. 4 shows a change in strain component values computed for the point of the highest intensity of micro-void development at the strain initial stage. At the point corresponding to a rapid increment in void fraction ($d/d_0 = 0.037$), values of components ε_1, ε_2, ε_3 amounted to 0.13, 0.17 and 0.033, respectively. The process of micro-void nucleation occurred for strains of 0.011, 0.014 and 0.0014. The specimen failure took place for strain components that reached the values of 0.61, 1.06 and 0.21. The value of the effective strain $\varepsilon_{ef} = (\varepsilon_{12} + \varepsilon_{22} + \varepsilon_{32})^{0.5}$ that accompanied void development amounted to $\varepsilon_{efdev} = 0.217$, whereas the effective strain at the instant of failure ε_{effail} was 1.241.

Micro-damage development in specimens with the notch bottom radius 4 mm demonstrates a slightly different character. The maximum in the stress graph is reached for the strain of 0.052 (Fig. 3a). Sudden growth in micro-damage volume fraction occurs a little later, after d/d_0 has reached the value of 0.11 (Fig. 3b). In contrast to $R = 1$ mm specimens, a more intensive development of micro-damage occurs in the specimen axis. At the instant of failure, the void volume fraction amounted to 0.33 in the specimen axis, and to 0.06 on the notch bottom surface. According to [3], the failure of a specimen of similar geometry ($R = 3.5$mm) occurred when the void volume fraction amounted to 0.26, which shows a good congruence of the results obtained.

Fig. 4 presents changes in strain components in the specimen axis. In the case discussed, ε_1 and ε_3 are radial components, therefore the dependence $\varepsilon_1 = \varepsilon_3$ holds (Fig. 2b). Strain components at void nucleation in the specimen axis amounted to $\varepsilon_1 = \varepsilon_3 = 0.0005$ and $\varepsilon_2 = 0.003$. For the strain value $d/d_0 = 0.11$ (the start of the sudden micro-void development process), strain components at the point reached the values $\varepsilon_1 = \varepsilon_3 = 0.11$, whereas $\varepsilon_2 = 0.22$ (the effective value $\varepsilon_{efdev} = 0.269$). The specimen failed when $\varepsilon_1 = \varepsilon_3 = 0.14$, and $\varepsilon_2 = 0.63$ (εeffail of the value of 0.66).

By conducting comparative analysis of results obtained for specimens $R = 4$ and $R = 10$mm, numerous analogies can be found. The strength of specimens with 10 mm notch was obtained for the strain of 0.052 (Fig. 3a). Similarly to the previous case, the sudden development of micro-voids occurred when the material strength was exceeded, at the strain of 0.08 (Fig. 3b). It should be noted that the intensity of micro-void growth was decidedly higher in the specimen axis. At the instant of failure, the void volume fraction at that point amounted to 0.1.

The character of strain increment at the point (in the specimen axis) is similar to linear (Fig. 4). The dependence $\varepsilon_1 = \varepsilon_3$ holds, like before. Strain components at void nucleation were $\varepsilon_1 = \varepsilon_3 = 0.0008$ and $\varepsilon_2 = 0.003$, whereas at the onset of rapid micro-void growth, strain components were $\varepsilon_1 = \varepsilon_3 = 0.09$ and $\varepsilon_2 = 0.19$. At the instant of the specimen failure, the following values were obtained: $\varepsilon_1 = \varepsilon_3 = 0.19$ and $\varepsilon_2 = 0.45$. Values of effective strains thus amounted to $\varepsilon_{efdev} = 0.229$ at the instant of micro-void rapid growth, and to $\varepsilon_{effail} = 0.52$ at the instant of failure.

On the basis of analysis of strain components at the points of fracture initiation, it should be stated that no matter what the case discussed was, the components on the loading direction (ε_2) showed the highest values. Rapid development of micro-damage occurred at effective strain values ranging from 0.217, for specimens with 1 mm notch, to 0.269, for 4 mm notch. The values obtained are presented in Fig. 5, which shows the dependence of the effective strain at the instant of void development on the corresponding degree of stress state triaxiality (determined numerically). Each point in Fig. 5 represents one type of specimen tested (differing in notch radius) and corresponding stress state triaxiality at the moment of sudden void growth. According to Fig. 5, with an increase in triaxiality degree, the value of strain necessary to start a rapid micro-damage development also grows. The difference in strain values between extreme points amounted to 24%.

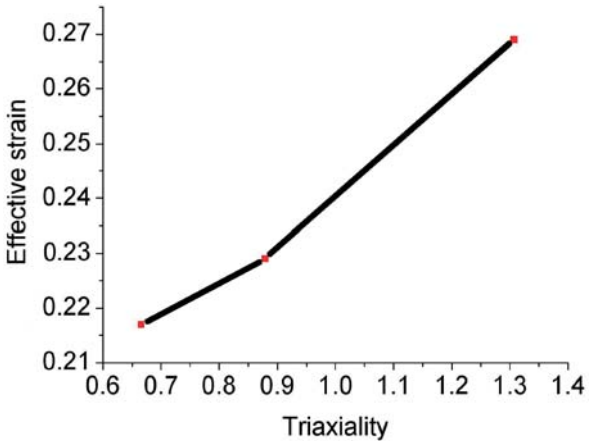


Fig. 5 Dependence of the strain accompanying rapid micro-damage development on the degree of stress triaxiality

The dependence that characterises strains accompanying specimen failure is of more complex nature. Then effective values ranged from 0.52, for specimens with R = 10 mm notch, to 1.241, for 1 mm notch. The character of changes in the effective strain is presented in Fig. 6. Each point in Fig. 6 represents one type of specimen tested (differing in notch radius) and corresponding stress state triaxiality at the moment of failure.

Within 0.7 – approx. 1.5 value range of the triaxiality degree, the dependence shows a degressive character. Yet, when the limit value of 1.5 is exceeded, the value of strains starts growing. For specimens under consideration, it was not possible to obtain triaxiality degrees higher than 1.678, hence examining further the character of the curve could not be performed.

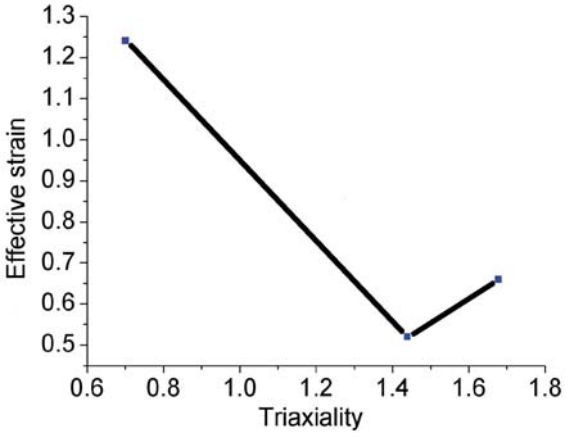


Fig. 6 Dependence of failure accompanying strain on the degree of stress triaxiality

It is supposed that strains of micro-void nucleation strongly depend on the material examined, primarily on the type of inclusions and precipitations. That provides an incentive to conduct numerical simulations at the microscopic level, and also to investigate other steel grades.

5. Conclusion

Numerical computation performed with GTN model made it possible to identify the areas of rapid micro-damage development, and hence the sites of initiation of ductile fracture. It was found out that for a sharp notch (R = 1mm), the failure process is initiated on the specimen surface. In specimens with relatively low degree of triaxiality (R = 4 and 10 mm), more pronounced micro-damage development occurs in the component axis.

It was demonstrated that a decrease in the material strength is strongly related to the process of the material internal micro-damage development. Void nucleation and growth in the specimen axis can be connected to an increase in the stress triaxiality degree. Such a relation was not found to exist for void development on the component surface.

Acknowledgement:

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Jan Janech – Tomas Baca *

DISTRIBUTED DATABASE SYSTEMS IN THE DYNAMIC NETWORKS ENVIRONMENT

This article describes a new architecture of a distributed database system, which is designed especially for the dynamic networks environment. Problems with the architecture of a traditional distributed database system are explained, and a solution is offered. The architecture introduced in this article does not intend to be a universal database system. It is a specialized solution for the implementation of distributed database systems in the dynamic networks environment.

1. Introduction

During 1980s distributed database systems (DDBS) went through turbulent evolution. Many various architectures and principles were developed most of them not very successful. Evolution slowed down in early 1990s [1, 7, 8]. In 1991 Valduriez and Ozsu published their book Principles of Distributed Database Systems [7] now considered a "bible" of DDBS.

Since then almost nothing has changed in the architecture of DDBS. Research has been focused on transaction management, replication management and fragmentation of database and basic principles remained untouched. However demands have changed. Many things, thirty years ago almost impossible, are now considered normal. Network architecture has changed; wireless networks are used much more often which brings complications like lower communication speed, more vulnerable channel and higher probability of interruption, etc.

These problems are much more significant in ad-hoc networks. Nodes in ad-hoc network are interconnected without any plan or topology. From the network's point of view any node can be connected and it will always work with the same basic principles. Traditional architectures of DDBS are not capable of working in such environment because complete detailed knowledge of the whole system and location of data is required.

We have already proposed a solution for these problems in [4]. In this paper we will go with the topic further and focus on processing of queries in the proposed system. However the basic principles of the new architecture are explained in the next section.

2. Basic Principles of the New Architecture

Traditional DDBS make use of Global Directory/Dictionary (GD/D), which stores mapping between local and global conceptual schemas of every site. Without the mapping the system would not know where the data are located and how to query them. Although improving performance in wired networks, GD/D poses a great barrier for DDBS being deployed in dynamic wireless network. Moving nodes bring frequent changes of network topology, thus the GD/D is difficult to maintain up-to-date. We have therefore proposed to replace GD/D by a different principle.

In a dynamic network every site knows its immediate surroundings only. So querying of a distributed database is fairly limited in such environment. The only sites which can be addressed to with queries, except the one which requests information, are those in the immediate surroundings in the network. This way the system naturally creates virtual clusters of sites that can communicate with each other. The clusters tend to overlap, thus one site usually can communicate with different set of sites than another site belonging to the same cluster.

This implies a possibility to move the directory from global level to cluster level. We call this principle Cluster Directory/Dictionary (CD/D). The directory contains only mapping of the global conceptual schemas of those sites that are accessible to the local conceptual schemas exclusively. However, there might be problems in this system due to clusters overlapping. Therefore the local conceptual schema of each site has to be mapped onto the global conceptual schema in several CD/D. Still, the question remains how to store CD/D in the cluster because there is no central site in the

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cluster, as it is strictly peer-to-peer system. The only possible way is to store it locally as described in [4]. Every site would have a mapping from the global conceptual schema onto its own local conceptual schema. The CD/D then consists of all of the local mappings in the cluster.

Executing local queries in such a system is very simple because all of the accessible data and all of the mappings are available, so there is no need to communicate with the other sites in the cluster. But since the queries are normally done globally across the whole accessible part of the database, the communication between the sites in the cluster is necessary.

3. Query Processing

Before a site can process a query, it would need complete CD/D, which is stored fragmented, every site in the cluster keeps its own local copy. Before the execution plan can be created the query site has to gather all the local copies. It would use broadcast messages. The whole process of querying is depicted by UML sequential diagram in Fig. 1. It can be separated to two sub-sequential phases:

1) *Gathering of CD/D.* Firstly the query site has to gather and process local fragments of CD/D. Because of dynamics of the network, it is possible that there would be no one to respond to the request or that the communication would be disrupted before it had been finished successfully. Therefore the query site has to stop waiting for the responses after a limited span of time. This phase consists of following steps:
   a) *Request for CD/D.* It is sent by query site in broadcast message. The query site also sets a period of time for waiting for responses.
   b) *The request is processed by other sites in the cluster.* Every data site receives the request and responses with its fragment of CD/D to query site in unicast message.
   c) *Processing of CD/D fragments.* After expiring the predefined period of time, the query node composes complete CD/D from received fragments.

2) *Executing the query.* With the knowledge of complete CD/D, the query node can start to execute the query. Firstly the query has to be decomposed to parts that can be executed by individual data sites. These components – subqueries are then sent to data sites. Subqueries are sent in unicast messages. After receiving responses the query node has to further process received data, because they are not necessarily what were originally requested for. Before returning them to the user, they have to be transformed into required form. This phase consists of following steps:
   a) *Global query optimisation.* This step can be executed even in the first phase. The most important is to minimise the amount of data that is to be sent back by data sites.

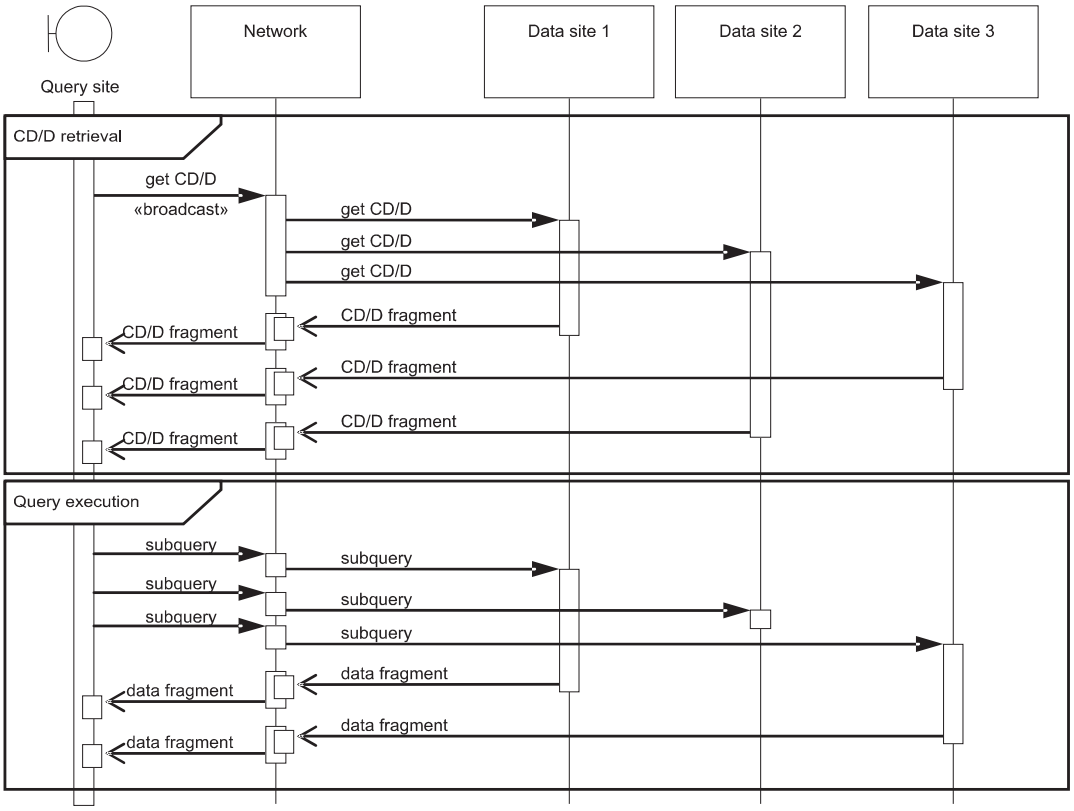

Fig. 1 Processing a query in the cluster

b) *Fragmentation of the query to subqueries.* The query site decomposes the query, set by the user, to subqueries addressed individually to data sites.
c) *Sending subqueries to data sites.* The query site sends subqueries to data sites in unicast messages. In respect of possible change of the cluster structure that might have occurred in the meanwhile, the query site has to set a span of time for waiting for responses.
d) *Local query optimisation.* Every data site optimises received subquery.
e) *Execution of subquery.* Every data site executes the subquery in its local part of the database that is accessible to it.
f) *Responding.* Every data site responds to the query site with requested data in unicast message.
g) *Evaluation of responses.* Received responses are not necessarily response to the request set by the user. The query site has to synthetise responses together.

This mechanism is rather complicated. The query site has to send two requests. The first one requesting CD/D is sent to all in one broadcast message. The second one requesting the data themselves is sent individually to every data site in unicast messages. The whole system has to be robust enough to deal with possible change of cluster structure at any time. Two types of changes can occur during the query is being processed:

- A new data site *joins the cluster* right after gathering of the CD/D. The query site would not however ask it for data because it does not know about its presence.
- A data site *leaves the cluster* right after gathering of the CD/D. The query site however counts with its presence while globally optimising the query and would have to go about evaluation of responses despite of missing response.

Therefore we simplified the process into the form depicted by UML sequence diagram displayed in Figure 2. The whole query is sent to the whole cluster in one broadcast message. Thus there is only one phase of processing the query, composed of the following steps:

a) *Global optimisation of the query.* The most important is to minimise the amount of data that is to be sent back by data sites.
b) *Sending the query.* The query node sends optimised query in a broadcast message. It will start to wait for responses for a limited span of time. The span of time must be estimated according to expected amount of data to be received. Every data site has received complete query.
c) *Fragmentation of the query.* Every data site decomposes the query and searches for subqueries, which it can locally execute.
d) *Local optimisation of subqueries.* Every data site locally optimises found subqueries.
e) *Execution of subqueries.* Every data site executes found subqueries.
f) *Responding.* Every data site responds with results of individual subqueries. However it also has to pack in executed subquery to every response.
g) *Evaluation of responses.* After the query site has finished waiting for responses, it synthetises final result of the query from received responses.

This algorithm does not suffer from aforementioned problems. The query site does not work with CD/D at all and needs only knowledge of Global Conceptual Schema. In case of cluster structure change during processing of a query receives the query site different set of data than it would receive if the cluster stayed unchanged. However the query site does not know about the change and therefore does not have to deal with it.

Each of both approaches would give the same results. The difference is that the former one is more complicated and includes more exceptional states it has to deal with.

4. Query Language

A query must be written in the format from which it is easy to extract the sub-queries so that data node can determine, whether it is able to perform some parts of the query in the pull method.

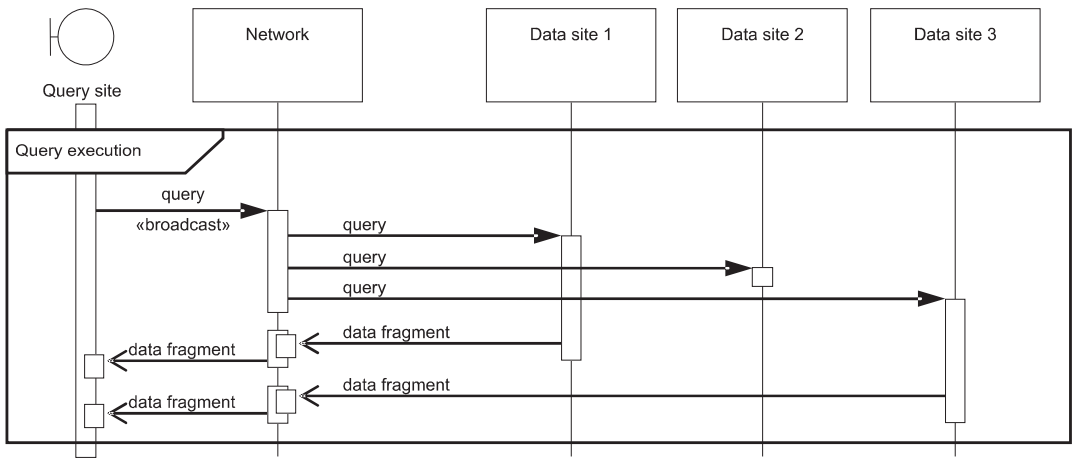

Fig. 2 Using broadcast message to send a query

The proposed system therefore uses object λ-calculus [3, 4], introduced in [6]. Object λ-calculus extends the classical λ-calculus by the possibility of working with objects and using relational algebra operations on object collections. Thus it retains the essential characteristics of classic λ-calculus and also allows the implementation of database operations. For extraction of sub-query in the object-λ-calculus the inverse operation to the β-reduction can be used.

Relational operations using the object λ-calculus can be written as follows [6]:

- access to an object property (attribute value)

```
object ◁ property
```

- selection operation

```
collection // (λ row | condition)
```

- projection operation

```
collection » {list of attributes}
```

- collection operation

```
collection » (λ row | condition)
```

- Cartesian product

```
collection1 × collection2
```

In addition, the proposed system introduces operations for the natural join operation:

- inner natural join

```
⋈ (collection1 × collection2)
```

- left outer natural join

```
⋈L(collection1, collection2)
```

- right outer natural join

```
⋈R(collection1, collection2)
```

- full outer natural join

```
⋈F(collection1, collection2)
```

For example SQL query

```
SELECT * FROM table WHERE id=10;
```

can be written using λ-calculus as:

```
table // (λ item | item◁ id = 10)
```

The query satisfies the first condition as any part can be executed separately.

5. Query Optimisation

With regard to rapid cluster structure changes the execution of query must be performed quickly. The query must be optimised in such manner so that data sites are able to process it in short time and have to transfer as little as possible data. The optimisation can be performed at two steps:

1. Global optimisation. It is performed at the query site. It tries to reorganise operations in the query so that amount of data sent back in responses is minimised.
2. Local optimisation. It is performed by every data site individually, which knows structure of local data by using Local Internal Schema and Local Conceptual Schema. It reorganises operations in query so that time required for execution is minimised.

The query site knows neither structure of the cluster nor organisation of data. It is therefore impossible to globally optimise queries for speed. The query site is unable to plan execution of subqueries for individual data sites or, in other words, to globally optimise amount of data. Unlike traditional DDBS it cannot even rely on replication of data and query for data from those sites which can access it most effectively. The query node can therefore base its optimisation only on knowledge of Global Conceptual Schema and knowledge of the query itself.

Secondly, data sites must not be expected to be able to access all the collections mentioned in the query. They are just expected to find out larger subquery they are able to execute and reply with the result of the execution. Operation with one collection (unary operation) can be executed if it has the collection accessible. However operations with two or more collections (multiary operations) are possible only if the data site can access all of the collections. Optimiser should therefore reorganise operations in such a way so that, if possible, unary operations are executed first, which minimises amount of data being processed by multiary operations.

We will illustrate the explained principles by following example:

```
⋈ (projects, workers) // (λ item | item◁projectName = DDBS)» {name, surname}
```

If a data site does have collection projects but does not have collection workers accessible, it is not able to perform join operation. It is therefore obliged to send everything from the collection projects even though the query site will later use only one record with the name DDBS.

However, by writing the query as follows:

```
⋈ (projects // (λ item | item◁projectName = DDBS), workers)» {name, surname}
```

the data site is able to perform the whole selection and would send through network only one record with the name DDBS.

Now imagine a different data site, which has only collection workers accessible. It has to response with the whole collection

workers even though the query site will, in the result, use only values of name and surname attributes.

By writing the query as follows:

```
⋈ (projects // (λ item | item◁projectName =
DDBS),workers » {name, surname})
```

the query site would not have enough information for join operation (it would lack information about attributes that should have been used – e.g. `project_id`). It implies that it is not possible to reorganise operations in an arbitrary manner. Every operation has to be executable even after optimisation which means that every required attribute has to be accessible. Moreover the resulting collection must not be changed either. Thus the optimisation has to follow these rules [3]:

- A unary operation cannot be moved in front of a multiary operation if it works with attributes of objects from several collections, which are used as parameters of the multiary operation.
- Unary operation collection cannot be moved. It transforms collection of objects of certain type to the collection of objects of different type. If the operation were moved in front of any other operation the new query would be even impossible to execute (because of collection item protocol change) or would be giving different results than the original one.
- Unary operation projection can be moved in front of binary operation join only in case that it returns all the attributes used by join.
- Projection can be moved in front of binary operations intersection, union and difference only in case that the list of operations is a subset of protocol of all original collections.
- It is always possible to move projection in front of binary operation Cartesian product.

6. Limitations of The New Architecture

The architecture introduced in this article does not intend to be a universal database system. It is a specialized solution for the implementation of distributed database systems in the dynamic networks environment. Therefore it has some problems which may prevent using the architecture in some situations.

It is impossible to do a lot of optimizations due to the fact that the GD/D does not exist. The sites do not even have access to the whole CD/D. Broadcast messages can also overload the network in case many queries are processed at the same time.

In most situations the querying sites do not have access to the whole database.

For the query site there is no way of how to find out whether it has already received all the data it has requested or if it has to wait longer.

It is impossible to provide referential integrity because the distributed database can be partially or even fully inaccessible.

This architecture allows just the read-only access to the distributed database. Destructive operations can be executed only locally on the data sites.

Poorly written queries can result in transfer of large amount of data and thus overload the network.

These limitations are results of the environment rather than the defects of the architecture. Thus the architecture can only be used when these problems are not limiting.

7. Conclusion

We can find many options how to use database systems in dynamic network environment. Ability to share public data stored in internal database of car [5] (e.g. information about parking places), to provide data specific to geographic location of the user (sharing maps) etc.

The present architectures are not suitable for such an environment. The proposed architecture removes their limitations; however it brings few of its own as a result of principles of dynamic networks.

In a short time a prototype of the system will be created so that its behaviour can be tested experimentally. It would be possible then to compare this new architecture with the existing ones.

Acknowledgement

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Lucia Vrablova – Milan Gregor *

COMPANY IN CRISIS

This paper deals with corporate crisis. It draws attention to the failing firm strategy in times of crisis. The corporate crisis is an important part of business life cycle. Proper crisis management is necessary for the survival of a competitive fight and staying on the market.

Keywords: *crisis, strategy, redevelopment, restructuring, competition, performance.*

1. Introduction

The current period is characterized by many changes. Constantly creating new products, new markets bring new opportunities but also threats. Each company tries to cope with the competitive environment and deliver the best possible competitive position. For success in business areas is not enough to accurately know business' environment. The understanding of internal processes is crucial to maintain a successful operation on the market. Measurement of corporate performance can be seen as a key factor in achieving a stable position in the market and gaining competitive advantage. Analyses of selected indicators help managers make good decisions with full knowledge of each other.

Achieved business results are diverse in market environment. Business success is contingent upon the choice and implementation of strategies for maintaining and growth of competitiveness. An appropriately chosen strategy leads to the proper direction of the company, or, at the time of corporate crisis to save the company itself.

Detailed analysis of corporate performance can determine the situation, the company is in.

According to Fig. 1 three main states of the organization have been generated:

- a company with a favorable state of performance,
- a company with less favorable state of performance,
- a company with poor results in performance.

2. Company with a favorable state of performance

The business environment is constantly faced with competing and fighting with a commitment to stay on the market. Company performance based on in-depth analysis is finding favorable situation a positive sign of the strategic actions of the management. To

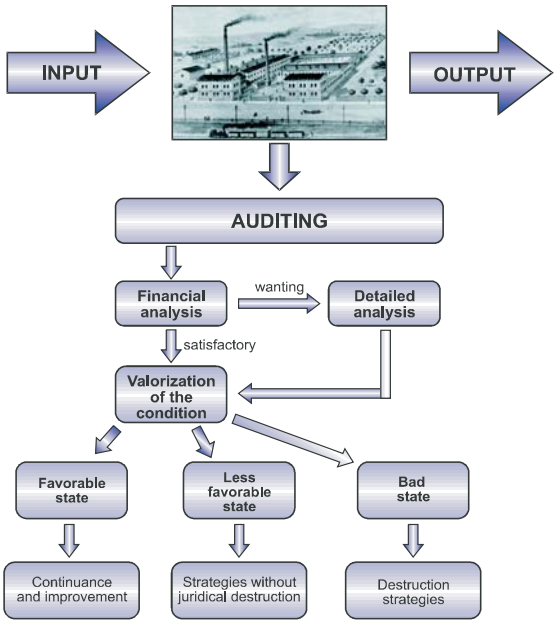

Fig. 1 Scheme of the decision [3]

maintain and to improve achieved state it is necessary to continue in process and strategic decisions improvement, which relates to enterprise focus, changes of range, markets, technologies, capacity and resources. As Blasko [3] introduces, one of the possible ways how to ensure the effective course of the enterprise in a changing competitive environment, is the management based on an appropriate forecasting of future activities in the long time terms. He designed a supportive decision-making system that was developed for the managers and is one of the crucial systems supporting good decisions making. The structure of the system provides a good set of tools for creating and evaluating potential alternative solutions of real situations.

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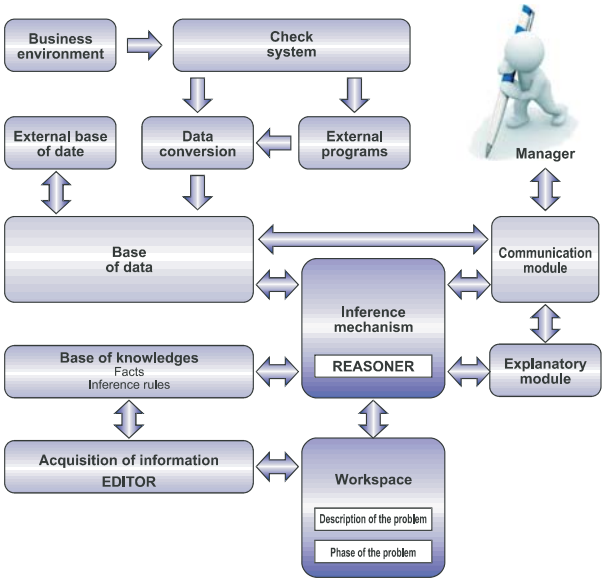

Fig. 2 Scheme of the decision (according to [3])

This model can be recommended for firms situated in the good values of corporate performance. The system allows a quick and effective monitoring of the production and economic activities and their multilateralism enables making of strategic decisions aimed at the maintaining and improving the current situation [3].

3. Enterprise with less favorable state of performance

There is a significant number of companies going into bankruptcy from day to day, but it is a longer process, during which certain characteristics and phases can be monitored. As Synek [1] introduces, for the first phase of business crisis is mainly typical decrease of performance. In the second phase decrease of profitability follows, the next phase is characterized by increased working capital need, and in the fourth phase the adjustment of capital structure is failing. In the last phase the company denotes insolvency hence lack of liquidity of the company. In order to take various measures, it is necessary to determine the specific case-history of the company, hence identification of the causes, nature and development stage of the crisis.

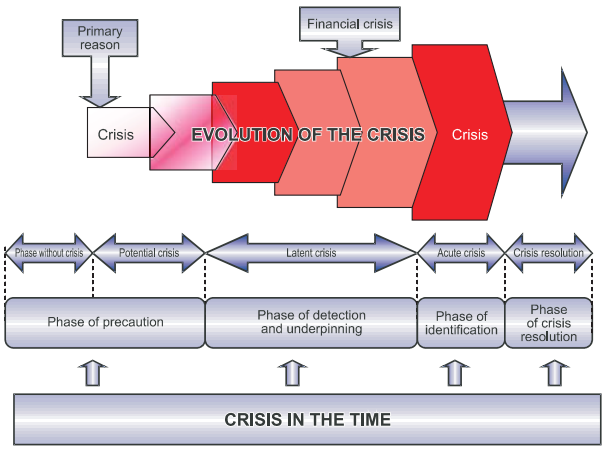

Fig. 3 Crisis at the time [2]

Zivcak [2] characterized predicamental enterprise's development as a time series of predicamental conditions obtaining a continuous nature and, to a large extent, representing predetermined orientation of their next movement at the time.

The crisis formation is subject to causes which can be divided into internal and external. It is possible to affect internal causes by permanent analyses and evaluations within a company. These causes are, for example, decreasing outputs, liquidity problems, reducing of profit margins etc.. More complicated situation is when crisis arises because of external factors. In such a case, there are certainly factors which company cannot affect, but their influence has a major impact on the overall economic situation. Such factors include economic factors (such as life-cycle phase), financial (development of financial market instruments), or monetary factors (changes in interest rates).

The second step is needed to define the nature of the crisis, whether it is a strategic crisis, crisis caused by economic results, or a liquidity crisis. Strategic crisis is a crisis caused by wrong strategic decisions, such as improper allocation of areas of business, improperly selected portfolio of products, or investment strategy which causes excessive production capacity. Causes of the crisis created by the action of profit are high prices with respect to the absorption ability of the market, high personnel costs, and errors in business financing, or inappropriate target of investment. The liquidity crisis is usually caused by prolonged violation of fundamental rules of financial balance, a low level of receivables and inventory management care, or large investments in excess of the company ability [2].

The most common symptoms that can be seen when the company is in the state of threat are the loss of liquidity, a temporary decrease in sales, or excessively high gearing ratio. If early detection of threats state is done, strong likelihood of right corrective arrangements or survival strategies exists. The task of the survival strategies is to ensure existence of a company and prevent the possible extinction.

Enterprise located in a state of emergency may be managed using the survival strategies without the legal and property extinction of enterprise.

Basic survival strategies without possibility of legal and property extinction of a company include:

- Consolidation – is the act of merging many things into one. In business, it often refers to the mergers and acquisitions of many smaller companies into much larger ones. In the context of financial accounting, *consolidation* refers to the aggregation of financial statements of a group company as consolidated financial

statements. We see IBM, Oracle and Microsoft buying up either specialty companies to fill out their portfolios, to get certain people in the fold, or to remove the competition.

- Restructuring is the termination of employees and reorganization of those remaining; it can include reductions in plant and equipment. Restructuring is usually implemented to realize cost savings. Quite often financial restructuring is used. Financial restructuring is a process geared at avoiding the liquidation of the company. Usually it involves agreement by third parties to satisfy creditors' claims under certain terms and conditions. Financial restructuring may also be carried out by concluding an agreement with all creditors of the company under which creditors will be paid on somewhat different terms than those initially accepted by the company when credit and loans were extended. This form of financial restructuring enables the company to continue its operations and minimize creditors' losses.
- Reengineering is a management tool that became popular in the late 1980s and early 1990s. Like many such tools, it aims to cut costs while at the same time increase productivity and provide higher levels of service. And while all this is true, reengineering still offers companies much more. The concept that is at the heart of all reengineering projects is the need to stay competitive in today's business world, and this broad concept involves costs, quality, productivity, and a host of other business elements.

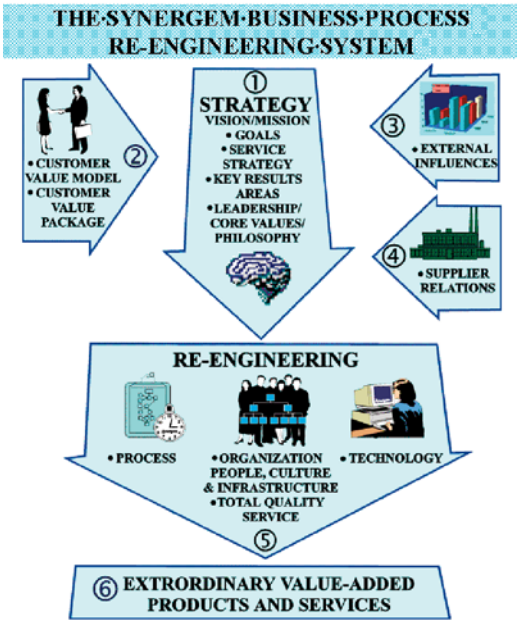

Fig. 4 Re – engineering process

- Rehabilitation is a restoration of an entity to its normal or near-normal functional capabilities after the occurrence of a disabling event.
- Management based on control contract includes negotiating the terms and conditions in contracts and ensuring compliance with the terms and conditions, as well as documenting and agreeing on any changes that may arise during its implementation or execution. It can be summarized as the process of systematically and efficiently managing contract creation, execution, and analysis for the purpose of maximizing financial and operational performance and minimizing risk.

4. A company with poor results in performance

Business solution of the crisis may be a strategy with the legal dissolution of the company. Such approaches are used in a situation when it is no longer possible to apply the above – mentioned reorganization strategies of a company. This group includes:

- Business Transformation is a change management strategy which has the aim to align People, Process and Technology initiatives of a company more closely with its business strategy and vision. In turn this helps to support and innovate new business strategies. Transformation and change is a critical issue for most organizations. Research shows that the failure rate of change programmes at 70–80%, many organizations are struggling.

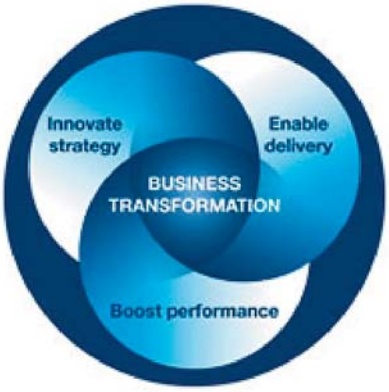

Fig. 5 Business Transformation

- Merger could be characterized as a combination of two or more separate entities for which a typical issue of securities.
- The acquisition occurs when one company buys shares in another company. In terms of the transaction, the target entity is clearly marked with the buyer, seller and the structure as well. For example the entity that is subject of purchase.

The currently ongoing wave of mergers, acquisitions and alliances in the world is very important to avoid difficulties which often manifest themselves after the merger partners. It is possible to establish a total of 12 conditions for the successful completion of the merger.

1. Strategic partners harmony – there must be a fundamental compatibility of products, markets and strategies and the harmony of the corporate culture cannot be forgotten.
2. Prevent leaks – there is often the case, especially if the result of prematurely disclosed to the media.

3. Active management and board – requires the utmost care and management of the entire merger process.
4. Involvement brightest personalities.
5. No one may be the audience – each member of its management whose project must assume a specific role.
6. Clearly and precisely formulated vision – being a clear framework and direction of negotiations.
7. All measures implemented quickly – so the process was completed within 2–3 years. Priority should be measures with far-reaching effects.
8. Clearly defined priorities – and gradually increase the complexity and complexity of merging organizations.
9. Each step proved to be clear and concise.
10. Content integration process must be transparent – in order to achieve synergies.
11. One non-bureaucratic – joining the two businesses is a good opportunity to remove obsolete organizational structures and working practices.
12. Keep the main goal – for each merger, more growth, better profitability and improved market position for the company is allowed.

5. Conclusion

Managerial decision making is a complex issue whose consequences are wide and directly affect the entire enterprise. Only detailed knowledge of internal links within an organization helps managers to make good decisions. Currently, after the economic crisis, many companies found themselves in an unfavorable financial situation, especially business on the brink of crisis. Crisis solution is possible by various strategies, either with a change of property and legal form, or destructive policies. Properly chosen strategy helps the company to gain a market position and continue in struggling in a competitive environment.

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Milos Ondrusek *

CHINESE ECONOMIC SUCCESS – INSPIRATION FOR ECONOMY, POLICY AND SECURITY

This paper focuses on the recent changes in global economic relations and increase of China's importance in global politics, security and economy. It describes the changes in China's security, economic, political strategy and its influence to its own development and empowering its position in international economic, political and security relations. The implications for the EU security management are described, too.

Keywords: *China, economic security, sustainable development, soft power, strategic investments, Africa*

1. Introduction

Nowadays, there are several serious turbulences and breakings of an economic, social, political, and security balance of the world economic system. We live in a difficult period of global economic, political and security order transition. This, together with acceleration of scientific improvement as well as with increasing complexity of multidimensional structure of risks and threats, is source of need for taking predictive strategic (economic, environmental, social, security and political) decisions related to the future development of global economy.

It is possible to state that the disintegration of the socialistic block, the end of the cold war, and the end of bipolar world order can be seen as the causes of necessity for the separated states and integration units to take transition:

- from existing, operation and development in somehow limiting, but very stable environment from an economic and security balance point of view,
- towards the existing, operation, and development in very unstable conditions of transitioning world economy.

This creates a requirement for a development of new socio-economic and security strategies on a national or international (union) level.

2. Actual Changes in Global Economy Related to the Political Economic and Security Position of State in Global Economic Space

It is possible to identify a significant trend to transition from bipolar world economy and security towards multipolar one, within the evaluating of present state of global economy and policy. Following theoretical options of future world order can be identified: unipolarity, bipolarity and multipolar development of the world.

It is possible to take into the account these theoretical possibilities as the result of present global economic, political and security transition:

- Unipolarity (that means a dominant position of one country or integration unit, which is perceived as hegemonic or dominant key player of international economics, politics and security in the world global economy.)
- Bipolarity (that means an existence of dominant positions of two countries or integration units, which are perceived as dominant key players of international economic, political and security relations in the world. The development of both of them guarantees the social, economic, political and security balance of the world)
- Multipolarity – (that means an existence of several – (more than two) dominant centers of social-economic and security development. This creates a dynamic balance by the necessity of interactions with the other centers. This reduces bad sides of monopoly or semi monopoly situations in dividing world economic, political and security power.)

In relation to the presumption of unipolarity it is possible to say that in present state of world economic system influenced by the weakening of the US position there hardly exists a prognosis about a recovering its position of world hegemony or about the changing this position with another possible the most powerful country in future world development. It is caused mainly by the polycentric character of world socio-economic development. The most realistic presumption of being the most important country with principal influence to the global economy and policy says about potential of China or India or European Union. But Chinese huge economic development is not connected with the same level of development in the other areas of national social economic system. Problems can be identified in relative political isolation, in sustain-

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ability of the current rates of economic development because of the high level of energetic and raw materials demand of Chinese economy, social area, and demographic imbalance caused the one child policy preferred by the Chinese authorities in the second half of the 20th century. Problems in future development of India can be viewed in the lack of institutional and democracy development.

Returning to the bipolar order in global economy seems to be unlikely because of current state of global economy development with significant trend of arising several new significant centers of social-economic development, (for example an Asian new core of dynamic developing East Asian countries, China, India and the other countries called Asian dragons or tigers).

The most likely looks the variant of multipolar future economic, political and security world order with several relatively equivalent centers of social and economic development and political and security power. This implicates many new-dimensional restructured risks for the social-economic-political and security stability of the world economic system. The Key fact that the present transition of the world towards a polycentric world economy system order has not been finished yet, seems to be the most important.

It is just uncertainty and complexity, variability, and instability of current conditions of re-structuralizing international economic, political and security relations, which are creating new serious challenges for countries and integration units in relation to the setting up their future economic, political and security position in the frame of future global economy development.

From the security and crisis management point of view it can be stated that nowadays we are in the period impacted by the forming of future national security positions as well as forming the world security order by utilization long term stability and development factors of key areas of economy, policy, security in current unstable conditions of the world economic system.

The process of creation and forming the economic, national political and security position is in current state of world economic system influenced by:

- incomplete transition of world economic system from bipolar to polycentric order one,
- overcoming differences and borders of an autonomous seizing and position of single key national areas of operation and management in the global environment,
- increase of the complexity and multidimensionality of various real or potential determinants of future country development,
- increase of number, complexity, and interdependent multidimensional character of present risks as well as risks of future development of global economy together with development of the country or integration unit's position within it.
- impacts of global trends e. g. increase of regional disparities, decrease of ecological balance of environment, development of transport and IT technologies, acceleration of scientific development

This implicates the fact that nowadays it is neither possible nor effective to solve the key areas and problems of state existence in international environment separately without considering the synergic impact of the other ones. This is setting the need of change in seizing the basic aim of country existence and also the existence of its key subsystems.

The priority should not be seen in the maximization of growth in key indicators of a national development but its stability and future sustainability together with consideration of present and future threats of sustainable socio-economic national development. It is clear that in present state of globalization it is not possible to solve the economic affairs without considering the policy, security, ecology, etc. It is just an increase of complexity, which is the powerful stimulus for development of new security concepts as well as new conceptions of national development considering the recent changes in basic characteristics of global economic space. From this point of view it is just an economic strength and potential of sustainable development which create and enforce the national long term stability and security. Military way of securing the state security has been becoming inefficient. We can identify the increase of using the economic tools for securing the strategic security goals and objectives.

3. Strategic Investments in Africa – Important Component of an Economic Security Strategy of China

Former mentioned factors are in many countries main drivers of reevaluating their strategic activities in relation to their future security – economic and political position in global context of the world economic system.

China can be considered a significant representative of mentioned changes in seizing the concept of state development.

In context of recent changes in global economy, it is possible to state that China underwent serious, important changes in seizing its own strategic position and the priorities. It is in the process of developing its position in the global economy. Briefly, it is possible to depict the basic frame of mentioned changes in these points.

- Transition from absolutistic state directing internationally isolated economy towards relatively closed state centrally directed economy with increasing features of market economy.
- Transition from preference of military approach to prevention and solving of security affairs towards preference of soft power and economic tools using in international affairs and also in security affairs as a principal component of its own wider seized security strategy.

As a proof of outlined changes can be seized a long term high rates of economic development, incorporation of China to WTO and the other international structures, as well as developing China's economic and security position in the global economy.

Recenty we can identify three basic tendencies in Chinese using of economic tools to enforce its own multidimensionally seized security and politic position in global economy:

Growth of Real GDP of China in selected years compiled by author based on data of IMF[1] Table 1

Year	2005	2006	2007	2008	2009	2010	2011 (projected by IMF)
Growth of Real GDP	11.3%	12.7%	14.2%	9.6%	9.1%	10.5%	9.6%

- using the pro-export oriented foreign trade policy together with under valuating currency policy of Chinese currency, all this is focused on the supporting of Chinese exporters,
- gathering or reducing huge amounts of dollar reserves considering the economic and security priorities of China in relation to the China vs. US foreign policy objectives,
- trying to develop foreign trade relations with an African and Latino-American and Asian countries focused especially to securing cheap raw materials in long term horizon for high energetic demand of Chinese economy. There exists a tendency to achieve this objective through exchanging the long term mining concessions or permits for realization of huge infrastructural projects by Chinese firms in African and Latino-American states.

Recent economic development affected by present financial-economic crisis causes a decreasing advantage of cheap Chinese Juan. It is because of serious global demand failing. Principally, this strategy is guaranteeing economic success of Chinese exporters within the frame of recent rules, and level of international trade relations' liberalization.

Level and way of using the dollar reserves seems in recent situation of wakening USA currency position to be the controversial tool. It can be a source of Chinese pressure to USA and its foreign trade partners aimed to the correction of their activities in relation to the Chinese foreign trade policy and security interests. From the China's point of view there exists a real risk of appreciation of Chinese currency and distortion of Chinese economic proportions, or decreasing of US dept by using smart monetary policy focused to decreasing US dollar exchange rate. Another notable feature of Chinese economic and security strategy are efforts to achieve the increase of Chinese impact to the international policy and security thank to the Chinese strong international trade position on the global market.

It is best noticeable in the increasing amount of bilateral exclusive profitable trade partnerships with African and Latino American states.

The African continent seems to be a base of future long term economic development of China.

Although we can identify a Chinese demand for raw materials from the other less developed countries, we can state that Africa is the number one. It is documented by:" The chairperson of the Commission of the African Union, Jean Ping, commended China in January 2009 for its contributions to Africa and identified China as Africa's key strategic partner [2].

It seems to be the Chinese priority to establish a long term and stable social – economic and political relations among the China and African states It can be seen as the attempt of China to create a long term partnership as the guarantee of the social, economic, political and security development for both partners China and Africa too.

There are a lot of economic political strategic activities among the China and African states, which are not aimed only to the short term securing the exchange cheap African raw materials to the low rated loans or big infrastructure construction sites.

Chinese activities in Africa are wider. For example: In February 2009,China dramatically broadened its diplomatic support for Africa at a plenary session of the UN General Assembly, during which the Chinese ambassador declared: "In the reform of the Security Council, priority should be given to the greater representation of developing countries, in particular African ones" [3].

More African students now attend school in China than ever before (5,900 in 2007), most on Chinese-government-provided scholarships. China has pledged to "double the number of such scholarships by 2011" [4].

China has expanded the list of duty-free imports fromAfrica from190 to 440 items and is discussing a free-trade agreement with the Southern Africa CustomsUnion. Trade relations are further fostered by "commercial counselor offices in 40 African countries and seven consulates-general in five of them [4].

As proof of increasing importance of trade partnerships among the China and African states in China's foreign trade and security policy can be seen in the following figure

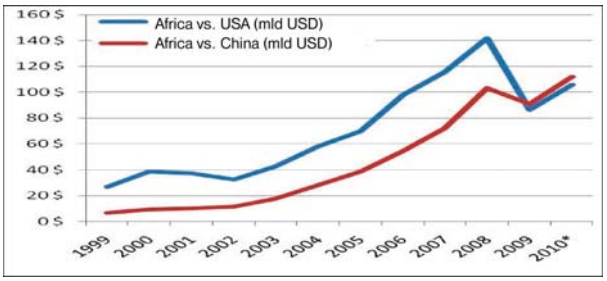

Fig. 1. Trade balance between Africa and China compared to trade balance between Africa and USA [5]

This figure shows development of foreign trade balance between China and African continent in comparison to the same statistics between USA and African continent. In Figure 1 we can see the basic increasing trend of both US and China's trade balance with

Africa. The most interesting period showed in the figure from our point of view is the period between the years 2008 and 2010. There can be seen a dramatic change in US vs. Africa trade balance. From the positive extreme increase in 2007, 2008 to huge drop in 2009 and its relative recovering on a lower level in 2009. This caused that China is the second in value of foreign trade with Africa just behind the EU. In the figure it is possible to see the serious impact of breaking recent financial and economic crisis to the US economy and to the US vs China trade relations too.

In the figure 1 it is possible to identify two serious effects. The first is that the recent financial and economic crisis did not affect China crucially. This is caused by the fact that China was not the source country of crisis, next by the fact that China increased its orientation to the national internal market. It helped to decrease an impact of the recent crisis thank to the large scale of China's national market. The second economic efficiency and profitability of Chinese exporters slowed the fall of the traded value between China and Africa.

Taking into account the activities of China and the U.S.A., which are focused on ensuring the future sources of economic development, it can be stated that in the current reality of exhausting natural resources we are witnesses of a fight for raw material base (mostly) from the African continent. Especially ensuring resources for future development of the country is considered as a strategic priority of state security. In the relation to the Chinese-American "fight for Africa (especially for its raw material base)", this is documented e. g. by the rising of Chinese and African trade balance from 6 billion USD in 1992 to 112 billion USD in 2010 [5].

We can observe two different approaches in this fight for the African resources. The U.S.A. tries to promote its interests in Africa through transnational institutions, in which it has a significant position, and its involvement in numerous military conflicts. On the other hand, China tries to promote business partnerships by the creation of long-term contracts based on the exchange of cheap natural resources for building a new infrastructure, with individual African states. This can be viewed as the strategic idea of economic and security strategy. It also can be viewed only as the necessity of Chinese economy because of its huge development and its technological amortization and high energetic intensity ratio. The truth lies somewhere in intersection of these alternatives. It is possible to state increasing importance and impact of China's position in international economics and security.

It has to be said that although the foreign trade balance between the EU and Africa is nearly three-time higher than balance between the Africa and China [5] the European union has a serious problem with structure and non development character of the trade relations and investments in Africa. Notable difference can be seen also in the managing of human resources as the important part of strategic investments in Africa. In comparison to the European Union, China tries to establish a large community of the Chinese people in African states. This is really strategic in relation to the future development of China.

This one will allow to create new markets for Chinese production, it will accelerate the socio-cultural compatibility of both cultures, it will improve the negotiating position against the other states in the strategic talks with African states, it will allow to get the cheap African raw materials and also to export China's social and economic problems to Africa. (For example. export of the Chinese unemployment into the African states. etc.)

4. Summary

China is improving its economic and security position by orientation to the non military sources of development. Most of all it is achieving this by the smart using of economic tools for securing its future development. By this, China is significantly empowering its security in the global context. It is worth discussing if China is oriented to the economic security tools using in Africa only for its smart strategy of securing sustainability of its future development or it is only reaction on its recent acute problems in its national scale with dissatisfied demand for energies and raw materials. Long term activities of Chinese economic diplomacy and foreign trade policy are signs of strategic accent of the mentioned priorities of China in Africa or in using tools of economic security to improving its recent and future security too.

China can be thought to be an example of changing a view to the security and economic security in the global context. There can be identified a change from orientation on the securing ability of using military power to defend own economic capacities and interests in time, to the orientation on improving the soft power and economic tools usage. This is aimed to the securing the China's political, security and economic foreign trade position in the global context.

The sustainability of economic growth can be seen as the problematic issue, This is potential problem because of demographical imbalance of Chinese economy, as well as because of the process of arising more than two centers of development in the global economy.

It is clear that in recent world conditions and state of socio-economic development it is just the using of economic tools to be the important component impacting of strategic development of the states.

At the end we can state the serious impact of Chinese foreign trade activities to the selected African countries. In a long term horizon it is necessary to consider the empowering of China's position in Africa. It is really competitive and dangerous for the energetic and raw material stability of the world.

It is necessary by the effective foreign-trade policy to create opposition to the Chinese imports of cheap African natural sources. It is necessary because of the possibility that the African sources can be used by China for achieving the economic, political and military domination in the global size.

The activities of China have opened the question of insuring the material, energetic security of EU in a long term perspective. There is also a question of revaluation of the geopolitical priorities of EU arising. Finally it can be stated that this paper correctly shows that rising economic cooperation of China with African states is not a kind of soidarity more developed China with less developed African states as the recall on the period when the China was less developed and isolated country, nearly as poor as present Africa. Mentioned economic activities of China in the African continent are manifestation of clear geopolitical strategy aimed to the arising the China's influence in territory which will be the material base for future economic domination in the period of exploited resources.

It should be a priority of security, and crisis management to insure EU position in recent Fight for Africa by the activating proactive investments processes and restructuralizing its export and import in relation to the long term objectives of sustainable development of the European Union.

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Ondrej Cyprich *

APPLICATION OF UNIVARIATE TIME SERIES THEORY TO PASSENGER DEMAND FORECASTING

The methods, which are used for the purpose of passenger demand forecasting by Slovak transportation companies at the present time, are considerably simplified, and what is more, they are not already considered to be accurate. These limitations might be caused by insufficient research in this area over last years. Purpose of this paper is to identify a statistical model of passenger demand for suburban bus transport which satisfies the statistical significance of its parameters and randomness of its residuals. Three different methodologies – exponential smoothing, multiple linear regression and autoregressive models were used in order to identify more accurate and reliable statistical model compared with nowadays used ones.

Keywords: *Passenger demand. Demand modelling. Short-term demand forecasting.*

1. Introduction

Statistical modelling and forecasting of passenger demand by using univariate time series theory is probably one of the most common forecasting methods used for work with periodic time series data. This methodology has been successfully applied in the sphere of urban transport [1, 2] and in recently published models of passenger (carried per school reduced [3, 4] and normal fare [3, 5, 6]) demand for suburban bus transport. The main goal of this paper is to introduce method of the statistical modelling of passenger (carried per school reduced fare) demand by using univariate time series theory which appears to be more accurate and reliable alternative to automated forecasting procedures published in the literature [3]. In accordance with the main goal of the paper there was designed a statistical model which is suitable for short-term (forecast horizon $h \leq 1$ year) forecasting of passenger (carried per school reduced fare) demand for suburb bus transport in Zilina region. The most of analyses, modelling and forecasting procedures of the time series mentioned in this paper were worked out by using SAS LE 4.1 [7] and SAS 9.3.1 [8] software.

2. Materials and Methods

Properties of the used data, methods of its analysis, modelling and testing are briefly described in this section.

2.1. Properties and Adjustments of Input Data

Input data of experiments presented in the paper were counts of carried pupils and students collected by the cooperating carrier. These values were aggregated by summing so that an output of the aggregation process was monthly time series of passenger demand carried per school reduced fare $\{Q_p(t);\ 1 \leq t \leq 96\}$ (for period of months 1/2000-12/2007) in the Zilina Region.

Values in such a manner designed time series $Q_P(t)$ were considered to be spatially and substantially homogeneous as the carrier had changed neither his geographic scope nor transportation technology in the range affecting substantial and spatial aspects of the analysed time series within the specified period of months. "Trading day effects" were eliminated by own [9], passenger demand properties respecting, modification by Cipra [10] described calendar adjustment procedures. The output of the calendar adjustment process was fully homogeneous time series of passenger (carried per school reduced fare) demand for suburban bus transport $\{Q(t);\ 1 \leq t \leq 96\}$.

At first there were by subjective methods identified and later by objective methods properly confirmed – constant trend, monthly additive seasonality of $Q(t)$ time series in pre-forecasting analyses [9]. The models presented in this paper respect these properties completely.

2.2. Methods

Multiple regression, exponential smoothing and autoregressive models were used in order to statistical modelling of $Q(t)$ time series. The seasonal exponential smoothing model (method A) was developed and fitted by using exponential smoothing methodology. Smoothing state at time $t = 0$ of the model was obtained by Chatfield's backcasting method [11]. Smoothing weights (level α, sea-

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sonal δ) were determined so as to minimize the sum of squared one-step-ahead prediction errors:

$$\sum_{t=1}^{n} \varepsilon_t^2 \rightarrow \min . \quad (1)$$

Multiple regression was used in combination with Box-Jenkins methodology. The multiple regression (constant term with seasonal dummies) model combined with an autoregressive process of order $p = 1$ (AR(1) - method B) was used for the first time and then in the case of the multiple regression (constant term with seasonal dummies) model combined with an autoregressive/moving average process (ARMA (1,1) – method C). There were used practices and principles of linear stochastic models designing [10, 12] in the process of developing and fitting of $Q(t)$ time series models by using Box-Jenkins methodology. Applying this methodology were designed three autoregressive integrated moving average models of seasonal time series (ARIMA(1,0,1)$(0,1,1)_{12}$ – method D, ARIMA(1,0,1)$(2,1,0)_{12}$ – method E and ARIMA(1,0,1)$(1,1,0)_{12}$ – method F) – all without intercept parameter.

The statistical models presented in the paper were tested for compliance with the requirements imposed on mutual linear independence, stationarity and the normality of probability distribution of their standardized residuals ($\varepsilon_t = 1, ..., 96$). Mutual linear independence of models ε_t was tested by Bartlett´s test for autocorrelation [13] and Ljung-Box's χ^2 statistics [14]. Stationarity of the residual components was evaluated by augmented Dickey-Fuller's tests (ADF tests) [15] and Dickey-Fuller's unit root tests of seasonal time series (SDF tests) [16]. Normality of the standardized residuals probability distribution was tested by Shapiro-Wilk's (SW) [17] and by D'Agostino [18], Prins [19] and Filiben [13] described Kolmogorov-Smirnov's (K-S), Anderson-Darling's (A-D) and Cramér von Mises's (C-M) tests. Statistical significance of estimated parameters of the models was tested by Student's t-test [20]. These tests were conducted at significance level $\alpha = 0.05$ (except for the normality tests where higher values of significance levels ($\alpha = 0.15$) were used because of tests detection abilities).

3. Empirical results

The outputs of the forecasting procedures (analyses, modelling, testing) presented in the paper are goodness-of-fit statistics (Tab. 1), outputs of the randomness tests (Tab. 2) as well as evaluation of statistical significance of model parameters (Tab. 3). According to high volume of available outputs of computations they are presented only in considerably reduced form in the paper. Full outputs for all models including estimates of model parameters and their statistical significance evaluation, goodness-of-fit statistics, point and interval forecasts are part of dissertation thesis [9] and in the case of model estimated by using method E also in Perner's contacts [5].

In order to measure how well different models (methods A-F) fit the data there was computed traditional (root mean square error – RMSE, mean absolute percent error – MAPE) and penalty (Akaike's information criterion – AIC [21], Schwarz Bayesian information criterion – SBIC [22]) as well as extrapolational ($MAPE_3$, $MAPE_{12}$) goodness-of-fit statistics. Computed values of these measures see Tab. 1.

Based on the results of the tests for mutual linear independence, stationarity, normality of probability distribution and statistical significance of estimated parameters of the models seems the method E as the only one suitable for forecasting (ex-post, ex-ante) of $Q(t)$. The model (2) estimated by the method E showed very well fitting ability for actual data by its forecasts compared with other ones. Estimated values of its parameters with standard errors and outputs of their statistical significance tests (see Tab. 3).

Computed values of the goodness-of-fit statistics Tab.1

statistic	unit	method					
		A	B	C	D	E	F
RMSE	[1000 passengers]	4.795	4.746	4.690	5.772	5.691	5.965
MAPE	[%]	0.511	0.500	0.489	0.640	0.638	0.657
AIC	[-]	304.992	325.004	324.710	300.500	300.142	306.045
SBIC	[-]	310.121	358.340	360.611	307.792	309.865	313.338
MAPE12	[%]	1.076	0.866	0.989	.	0.977	0.939
MAPE3	[%]	0.806	0.802	0.776	0.748	0.626	0.744

Note: RMSE, MAPE, AIC and SBIC were computed by using the actual and forecasted values of observations in the period of evaluation (for a period of months 1/2000 – 12/2007), parameters of the models used for forecasting were estimated by applying observations from the same period of time. $MAPE_3$ and $MAPE_{12}$ were computed by using actual and forecasted values of observations in the period of evaluation (for a period of months 1/2007 -12/2007 – $MAPE_{12}$ and 10/2007 – 12/2007 – $MAPE_3$), parameters of the models used for forecasting were estimated by applying observations for a period of months 1/2000 – 12/2006 – $MAPE_{12}$ and 1/2000 – 9/2007 – $MAPE_3$.

Evaluation of tests for randomness of ε_t and statistical significance of estimated parameters of the models Tab. 2

Method	Statistical significance	Linear independence			Stationarity		Normality			
		BT-ACF	BT-PACF	LB	ADF	SDF	S-W	K-S	C-M	A-D
A	-	+	+	-	+	+	-	-	-	-
B	+	-	-	+/-	+	+	-	-	-	-
C	+	+	+/-	-	+	+	-	-	-	-
D	+	+	+	-	+	+	+	+	+	+
E	+	+	+	+/-	+	+	+	+	+	+
F	+	+	-	+	+	+	-	+	+	+

Note: Statistical tests provided "+"- satisfactory "-"- unsatisfactory "+/-"-boundary (satisfactory) results.

$$(1 - B^{12})Q(t) = \frac{\theta(B)}{\varphi(B)\Phi(B^{12})}a_t \qquad (2)$$

where:
B is the backshift operator, that is, $BQ(t) = Q(t-1)$,
$\theta(B)$ is the moving-average operator, represented as the polynomial in the backshift operator: $\theta(B) = 1 + \theta_1 B$,
$\varphi(B)$ is the autoregressive operator, represented as the polynomial in the backshift operator: $\varphi(B) = 1 - \varphi_1 B$,
$\Phi(B)$ is the seasonal autoregressive operator, represented as the polynomial in the backshift operator: $\Phi(B) = 1 - \Phi_1 B^{12} - \Phi_2 B^{24}$,
a_t is independent disturbance (random error) at time t.

Inappropriateness of other models to produce forecasts resulted from confirming autocorrelation of their ε_t by Bartlett's tests (BT ACF, BT PACF) or Ljung-Box's χ^2 statistics (LB).

Further use of the forecasted values requires consideration of the fact that model (method E) systematically underestimates reality. This accrues from the value of mean percentage error (MPE = = 0.087%) of this model. True values $Q(t)$; $t = n + 1, ..., n + h$ are likely higher than forecasted values.

Graphical output of modelling and forecasting by using the method E (see Fig. 1) where estimated values are expressed by smooth curve and empirical values by black points. The graphical interpretation of the actual (empirical) and forecasted values show that this model accurately describes the variability of empirical values of $Q(t)$. This fact is also supported by low levels of residuals of the model (displayed by the bar diagram in Fig. 1).

It was objectively proved that it is possible to reduce the confidence interval (3) around the estimator $\hat{Q}(t)$; $t = n + 1, ..., n + h$ (at the confidence level of 0.95), from ±200 to ±16 thous. passengers carried, compared with outputs of computations published by Konečný [3].

$$P(L_{95t} \leq \hat{Q}(t) \leq U_{95t}) = 1 - \alpha \qquad (3)$$

where:
L_{95t} is lower limit of the confidence interval,
U_{95t} is upper limit of the confidence interval,
$1-\alpha$ is given probability, called confidence level of the interval,
$\hat{Q}(t)$ is estimated value of passenger demand.

More detailed comparison of forecasting abilities and statistical properties of the method presented in the paper with statistical model designed by Konečný [3] in view of goodness-of-fit statistics inaccessibility was not possible. It is obvious that the increase of statistical model (method E) reliability defined by the reduced confidence interval (3) is also the attendant phenomenon of its increasing interpolation accuracy.

Estimates of SARIMA model parameters and outputs of their statistical significance tests Tab.3

Model parameter	Estimate	Standard error	t-test criterion	p-value
MA(1) - θ_1	0.33996	0.1222	2.7825	0.0067
AR(1) - ϕ_1	0.91483	0.0503	18.1999	<.0001
SAR(1) - Φ_1	-0.77398	0.1084	-7.1430	<.0001
SAR(2) - Φ_2	-0.42544	0.1068	-3.9824	0.0001

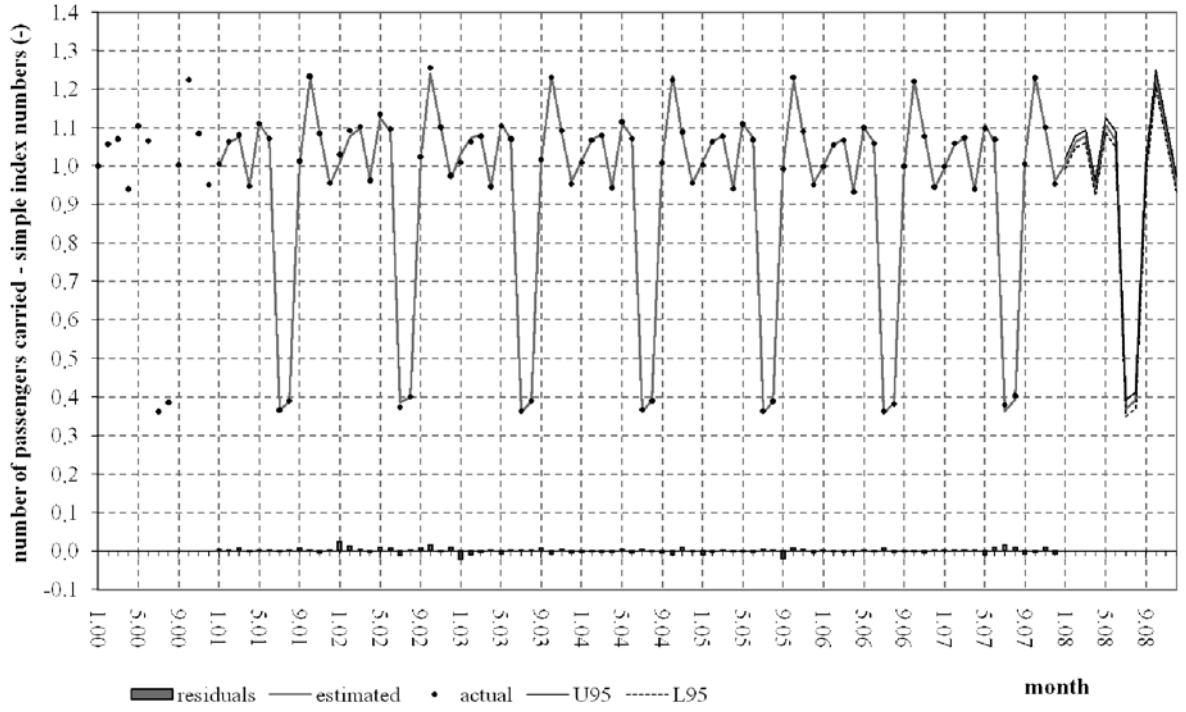

Fig. 1 Actual and estimated values of the Q(t) time series

Note: In order to protect interests of the cooperating bus transport company are values of Fig.1 presented in the form of simple index numbers ($I_{n/0}$). Reference value of the variable Q(t) is expressed in the base 1.0 in reference situation (t = 1, January 2000).

4. Conclusion

Outputs of the statistical tests of standardized residuals randomness and the values of goodness-of-fit statistics proved that the autoregressive integrated moving average model of seasonal time series ARIMA$(1,0,1)(2,1,0)_{12}$ without intercept parameter (method E) fulfils the requirements for statistical significance of its parameters, and what is more, mutual linear independence, stationarity and normality of probability distribution of its standardized residuals. The model presented in the paper is also because of these facts very good alternative to nonperiodic passengers demand time series forecasting methodologies [23, 24] and moreover provides more detailed monthly multi-step ahead forecasts. This model with respect to cross-regional differences cannot be considered as universally applicable throughout the Slovak Republic, but only in the Zilina region.

ARIMA$(1,0,1)(2,1,0)_{12}$ without intercept parameter presented in this paper despite the abovementioned restriction represents more reliable and more accurate passenger demand forecasting method in comparison with up to this time used ones. The attendant phenomenon of application in the paper described model in relevant transport company management is the reduction of manager's decisions uncertainty, and what is more, it can result in increase of company´s revenues.

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Pavol Durica – Marian Vertal *

VERIFICATION OF THE WATER TRANSPORT PARAMETER – MOISTURE STORAGE FUNCTION OF AUTOCLAVED AERATED CONCRETE – APPROXIMATELY CALCULATED FROM A SMALL SET OF MEASURED CHARACTERISTIC VALUES

The aim of the paper is to determine the moisture transport parameters for selected type of autoclaved aerated concrete using fly ash order to carry out the numerical analysis of the hygrothermal performance of selected building structures in real conditions. The moisture storage function (sorption, suction) and the liquid water transport coefficient are taken into consideration. Obtaining knowledge of these parameters involves a series of laboratory measurements and tests. Applying those parameters into modern calculation methods (WUFI) we will be able to analyse annual hygrothermal performance of porous concrete wall constructions in climatic conditions of Central Europe. This article aims to test use of a simplified approximating method to establish the moisture storage function for a chosen building material. Influences of the method on accuracy of the simulated calculation will also be analysed.

Key words: *moisture storage function, liquid transport coefficient, simulation tools*

Introduction

In order to predict hygrothermal performance of building components and elements, the computer simulation (HAM software) [8], requires moisture storage and transport properties data. The high quality of the material properties data, especially Moisture storage function and Liquid transport coefficient, are the basis for the modelling [10]. Implementation of moisture storage function (sorption, suction) and liquid water transport coefficient allows monitoring not only the water transport due to water vapour diffusion (Glaser model) but also receiving water and its redistribution due to capillarity. Obtaining knowledge of these properties involves a series of laboratory measurements and tests. Thus, the current simulation tools have only few material data files that cannot satisfy the increasing simulation requirements. Application of such "similar" material data – as proxy for the inexistent ones – within the simulation process is debatable. When the exactly measured data are not available and we want to avoid the data for similar material, we have an option to use approximating calculation from characteristic measured point. We can input specific materials, described by the material data, into the simulation tool as:

- a similar material taken from the database of the simulation programme,
- approximately calculated from characteristic measured point,
- precisely measured values for a concrete material.

The aim of this analysis is a comparison of given alternatives and their impact on results. We also monitor water content (water profiles and calculated course of the water content) inside a building's envelope. Construction material characteristic for the unified construction of panel housing in Slovakia between 1970–1972 were selected for the purposes of the present analysis. The result (measured and approximately calculated) is compared with a similar type of an autoclaved aerated concrete 600 (old style) from the simulation tool WUFI 4 [9].

1. Input processes

1.1 Selected building material used for analysing

This type of autoclaved aerated concrete listed below has been selected to be studied in the [8]. It was frequently used in constructions of residential houses, as well as non-residential buildings and production halls.

Autoclaved aerated concrete PB is a light concrete with silica filling – ash and gas silicate or more frequently gas concrete; mixed with foaming additive (aluminium powder) macropores are created (Fig. 1).

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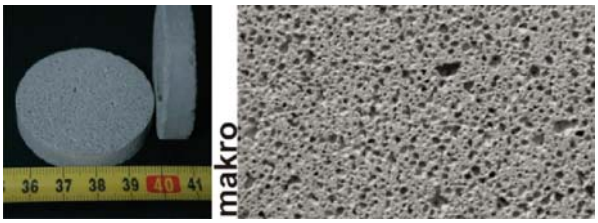

Fig. 1 Porous concrete PB specimens ready for measuring

It was used in single-layer external cladding of panel constructions systems (T 06 B, T 08 B – Fig. 2) of flat blocks, skeletal structural systems (e.g. MS 66, MS RP, S 1.2, BAUMS) in civic amenities (schools, shopping centres, etc.) and in type constructions of single- and double-layer flat roofs of the presented constructions.

Fig. 2 Panel block of flats structural system T08B, row and solo house Kosice

Its use grew significantly in large-scale development between 1970 and 1992 and it is still ranked among the most utilized building materials, however, its properties have been refined. 240 mm thick samples for the research purposes (6 core drills of 45 mm in diameter) were obtained from the walls of the panel structure T 08 B KE in Lunik 2 housing residential area, Kosice. The panels were manufactured in the former Panel Works Plant in Vranov nad Toplou (Hencovce), Slovakia, using Polish technology Unipol in 1964. The samples were taken in November 2006.

1.2 Analyzed building's envelope

A type of autoclaved aerated concrete compared to autoclaved aerated concrete 600 (old style) was used as a load bearing material. In simulation processes these alternatives were calculated:

- autoclaved aerated concrete 600 AC 600,
- aerated concrete PB (app. calculated) AC PB,
- aerated concrete PB (exactly measured) AC PB.

Cement lime plaster was used as external finish and gypsum plaster was used as internal finish (Fig. 3).

Fig. 3 Scheme of the analyzed building's envelope

1.3 Basic material characteristics – material data

The overview of basic material parameters is given in Table 1:

Basic material characteristics of used envelopes — Tab. 1

	AC 600	AC PB	CL ex.	Gint.
ρ [kg/m^3]	600	627	1900	850
p [%]	72	70	24	65
c [J/(kg.K)]	850	850	850	850
μ [-]	8	8	19	8,3
λ_{dry} [W/(m.K)]	0.14	0.14	0.8	0.2
w_f [kg/m^3]	340	528	210	400
A [kg/(m^2.s^{0,5})]	0.083	0.057	0.03	0.287
AC – aerated concrete, CL – cement lime plaster, G – gypsum plaster				

where ρ is bulk density [kg/m^3], p is porosity [%], c is specific heat capacity [J/(kg.K)], μ is water vapour diffusion resistance factor [-], λ_{dry} is thermal conductivity in dry state [W/(m.K)], w_f is free water saturation [kg/m^3] and A is water absorption coefficient [kg/(m^2.s^{0,5})].

1.4 Water transport parameters – material data

The main water transport parameters in buildings materials are:

- moisture storage function (sorption and suction curve),
- liquid transport coefficients,
- water vapour diffusion resistance factor.

1.4.1 The measured points of moisture storage function in low moisture range - Sorption curve

The sorption curve covers the sorption moisture region, i.e. hygroscopic range up to 97% (95) of relative air humidity (Fig. 4).

Measuring procedure of the sorption curve was carried out by the method of parallel exposure [8].

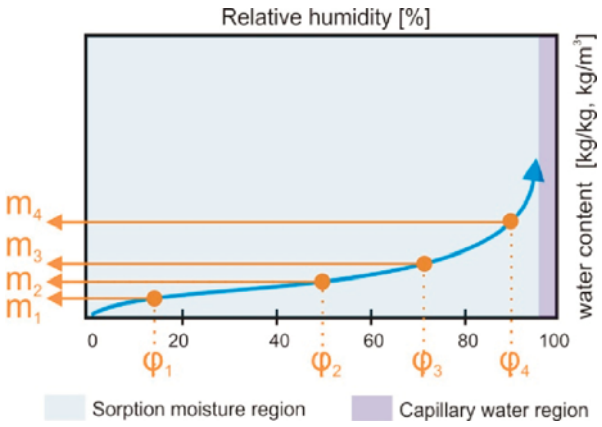

Fig. 4 Moisture storage function (sorption curve) of a porous material

1.4.2 The measured points of moisture storage function in high moisture range – Suction curve

Several measuring devices and techniques based on various physical principles can be used for measuring suction curve defining water accumulation in capillary water region Fig. 5. The method in which the determining measuring medium is water comprised in the sample was selected for the purposes of measuring the analysed materials. This method is referred to [2] as sufficiently precise, particularly suitable for the evaluation of the building materials whose porous systems have been exposed to external conditions (weather, pollution, impact of salts etc.). Measuring was conducted by means of pressure plate extractors produced by Soilmoisture Equipment Corp. [5, 6] – Figs. 6 and 7.

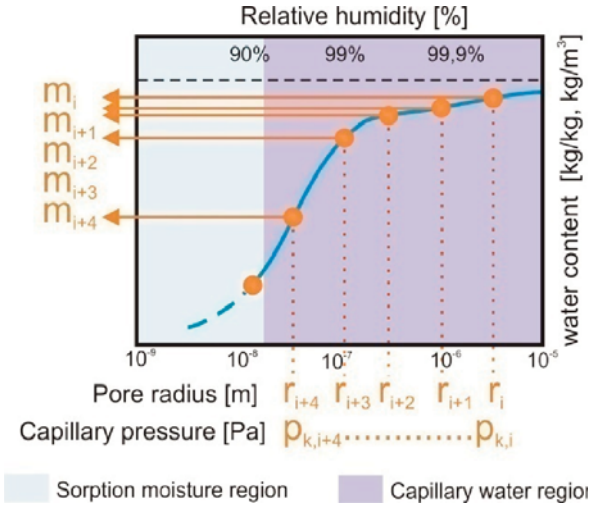

Fig. 5 Moisture storage function (suction curve) of a porous material

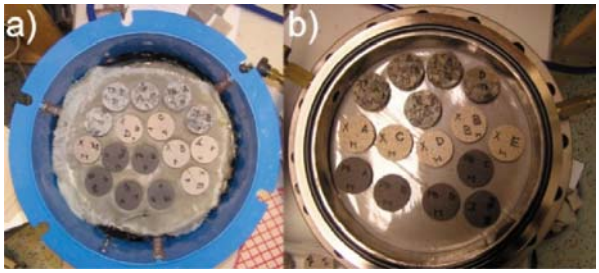

Fig. 6 a) pressure plate extractor PPE, b) pressure membrane extractor PME before setting pressure level

The concept of measuring lies in observations and recording of water weight loss in the saturated sample corresponding to the pressure inducing the change (see Tab. 2 and 3). Fig. 9 shows schematic connection of pressure plate and membrane extractor.

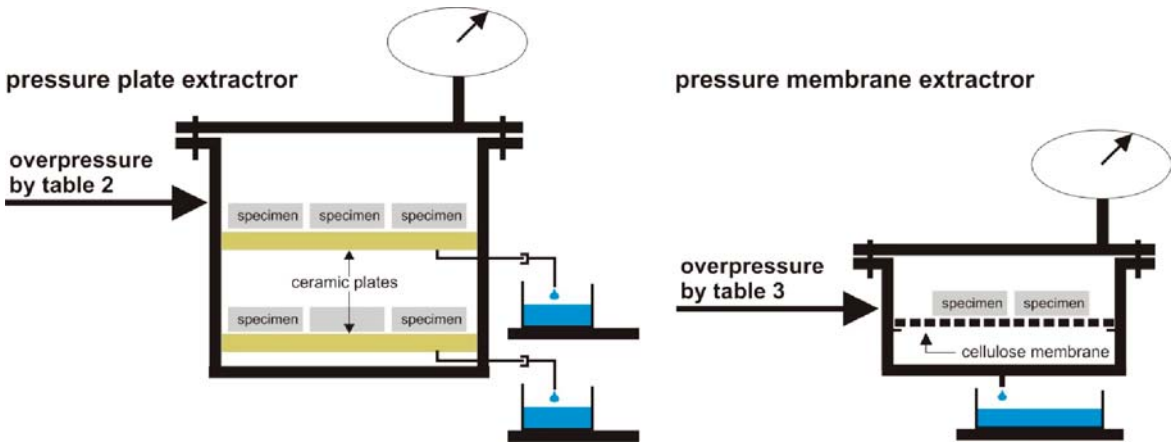

Fig. 7 Pressure plate (PPE) left and Pressure membrane (PME) extractor right

Suction pressure set points (PPE) Table 2

Apparatus	Pressure Plate Extractor							
Pressure level (i)	1	2	3	4	5	6	7	8
Pressure [Pa]	10^2	$10^{2,5}$	10^3	$10^{3,5}$	10^4	$10^{4,5}$	10^5	$10^{5,5}$
Pressure [bar]	0.001	0.00316	0.01	0.0316	0.1	0.316	1	3.16

Suction pressure set points (PME) Table 3

Apparatus	Pressure Membrane Extractor		
Pressure level (i)	9	10	11
Pressure [Pa]	10^6	$10^{6,5}$	10^7
Pressure [bar]	10	31.6	100

1.4.3 Approximate calculation of moisture storage function in low and high moisture range

The moisture storage function was approximately calculated by equation 1 [1]:

$$w(p_k) = \frac{w_f}{1 + \left(\frac{\rho_w \cdot r_p \cdot T \cdot \ln \Phi}{p_{k1}}\right)^{pk2}} \tag{1}$$

where

$$p_{k1} = e^{\left\{\frac{\ln p_{k,75} \ln\frac{w_f - w_{97}}{w_{97}} - \ln p_{k,97} \ln\frac{w_f - w_{75}}{w_{75}}}{\ln\frac{w_f - w_{97}}{w_{97}} - \ln\frac{w_f - w_{75}}{w_{97}}}\right\}} \tag{2}$$

$$p_{k2} = \frac{\ln\frac{w_f - w_{75}}{w_{75}}}{\ln\frac{p_{k,75}}{p_{k1}}} = \frac{\ln\frac{w_f - w_{75}}{w_{75}}}{\ln p_{k,75} - \ln p_{k1}} = \frac{\ln\frac{w_f - w_{97}}{w_{97}}}{\ln p_{k,97} - \ln p_{k1}} \tag{3}$$

where ρ_w is the water density [kg/m^3], $r_p = 462$ J/(kg.K) is the gas constant of water vapour and p_{k1}, p_{k2} are free parameters [-].

Moisture storage function for AC PB (measured and approximately calculated) [8] compared to AC 600 (old style) (WUFI 4) are shown in Fig. 8.

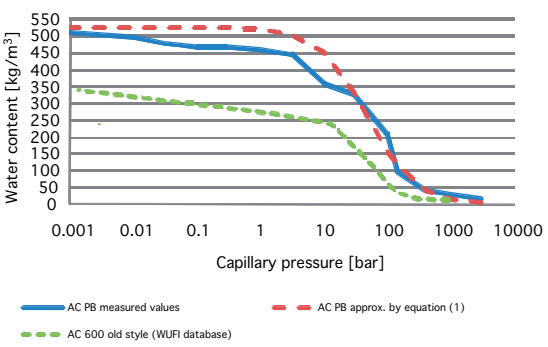

Fig. 8 Moisture storage functions for AC 600 (WUFI 4) and AC PB (measured and approximately calculated)

1.4.4 Liquid transport coefficient

Liquid transport coefficients were approximately calculated by equation (4) [3]:

$$w_f \frac{A^2}{(w_f - w_{80})} = \frac{4(D_{wf} - D_{w0})}{K\pi \ln\left(\frac{D_{wf}}{D_{w0}}\right)} \tag{4}$$

$$K = 0{,}025 \cdot 10^{\left(-0{,}4 \cdot \left(\log\frac{D_{wf}}{D_{w0}}\right) - 3\right)} + 0{,}61 \tag{5}$$

where D_W is liquid diffusivity [m^2/s], $D_{W0} = 2.10^{-10}$ m^2/s is liquid diffusivity by reference water content, hygroscopic range – constant, D_{wf} is liquid diffusivity by free saturation [m^2/s].

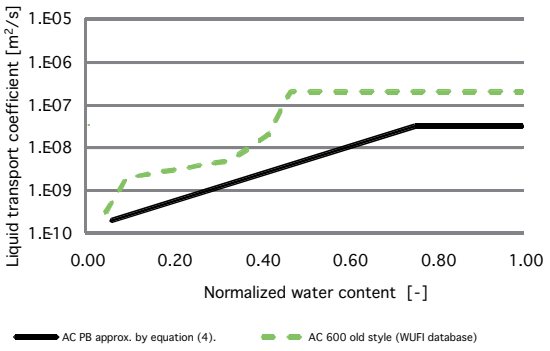

Fig. 9 Liquid transport coefficients for AC 600 (WUFI 4) and AC PB (approximately calculated)

Liquid transport coefficients for AC X and AC PB compared to AC 600 (old style) (WUFI 4) are shown in Fig. 9.

Water transport parameters for alternatives of simulation — Table 4

	AC 600 old style similar data	AC PB approx. calculated	AC PB measured
Moisture storage function	database WUFI	approximately calc. by the eq. (1)	measured
Liquid transport coefficient	database WUFI	approximately calc. by the eq. (4)	approximately calc. by the eq. (4)
water vapour diffusion resistance factor	constant value database WUFI	constant value measured	constant value measured

2. Simulation

2.1 Initial and boundary conditions

As boundary conditions in the exterior we used climatic data for Vien, Vien Hohe Varte (halfsynthetic long-year climate data set 1976-2005) (WUFI 4). On the interior side we had values given by EN 15 026, normal moisture load respectively. Initial conditions corresponded to values of interior temperature and relative humidity. The simulation was done for 3-years period (1. 10. 2011 – 1. 10. 2014).

2.2 Mathematical model

The analysis was realized by the simulation tool WUFI (WUFI 4),- a 1D analysis of heat and water transport as described by Kunzel. In Kunzel's model, moisture and heat balance equations are formulated as [4]:

$$\frac{dw}{d\varphi}\frac{\partial\varphi}{\partial t} = \nabla\cdot\left(\left(D_\phi\nabla\varphi + \delta_p\nabla(\varphi\cdot p_{sat})\right)\right) \qquad (6)$$

$$\frac{dH}{dT}\frac{\partial T}{\partial t} = \nabla\cdot(\lambda\nabla T) + h_v\nabla\cdot\left(\delta_p\nabla(\varphi\cdot p_{sat})\right) \qquad (7)$$

where dH/dT is the heat storage capacity of the moist building material [J/(m^3.K)], φ the relative humidity [%], δ the water vapour permeability [kg/(m.s.Pa)], p_{sat} the partial pressure of saturated water vapour in the air [Pa], h_v, the latent heat of evaporation of water [J/kg], λ the thermal conductivity [W/(m.K)] and T is the temperature [°C].

The liquid water transport coefficient is defined as:

$$D_\phi(w) = D_w(w)\cdot\frac{dw}{d\varphi} \qquad (8)$$

3. Output processes – results

Fig. 10 shows water profiles for aerated concrete 600 (old style) from the WUFI database and aerated concrete AC PB (measured and approximately calculated see Tab. 4) at three moments (18. 04. 2012, 26. 4. 2014 and 1. 10. 2014).

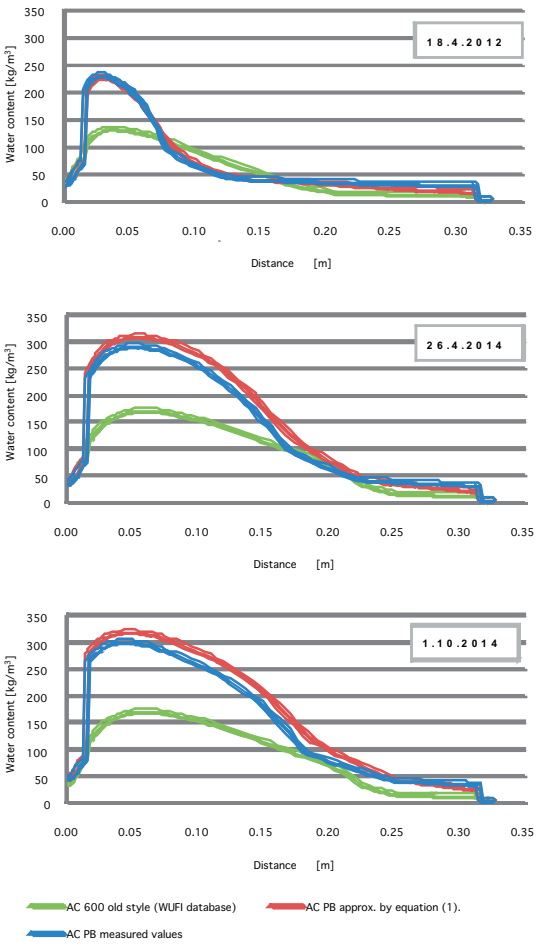

Fig. 10 Water profiles for AC 600 and AC PB (measured and approximately calculated)

Fig. 11 shows courses of water content within the simulation interval (1. 10. 2011 – 1. 10. 2014). As the graphs in Figs. 10 and 11 shows the water content stored within the building construction differs. In the case of the selection of similar materials (in this case autoclaved aerated concrete 600 old style) water profiles as well as water courses differ significantly. The difference is up to 38%. It is clear from this analysis that use of similar materials instead of concretely measured data can lead to significant mistakes in calculations. The water profiles, data from which are approximately

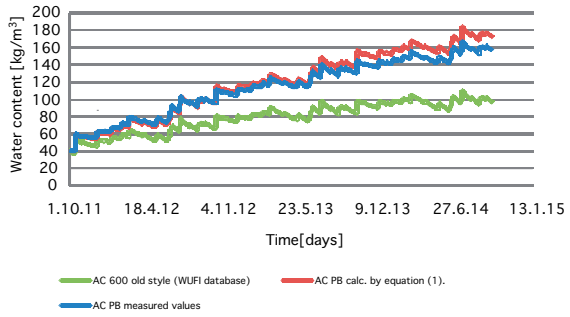

Fig. 11 Courses of water content for AC 600 and AC PB (measured and approximately calculated)

calculated (equation 1), copy the profiles calculated from exactly measured values. The difference is significantly low (under 10%).

Conclusion

Constant improvement of simulation tools is a natural expression of developments of the human society. Today, moisture inside of building envelopes is evaluated according to approximate models of calculations. These are based on so-called Glaser's, normally stationary, principles. This simplified procedure is not capable of recognising real processes happening with a building material, or to evaluate its behaviour during the analysed period.

On the other hand, there exist modern, normally non-stationary and very precise simulation tools. As the present numerical analysis showed, sensitivity of these methods to quality of input data is very high. Where relevant input data exist, application of simulation models is very broad. They offer a broad range of outputs that allow analysis of little used building materials directly in their natural built-in climactic conditions. As argued also in references [1] and [7], approximating relations are based on measuring characteristic points that are sufficiently exact to be used in simulation tools (HAM software) in the area of Building physics.

Correctly calculated results can be also used as:

- analysis of influence of ETICS on hygrothermal performance in any analysed building,
- analysis of influence of new surface material layers (exterior and interior) on drying capability of a building,
- analysis of influence of immediate amount of water in a material on levels of its thermal conductivity, within the context of a non-stationary U value, and on the related transmission heat loss coefficient connected,
- analysis and optimisation of details of building constructions with a help of 2D hygrothermal analysis,
- analysis and prediction of creation of mould growth with using the WUFI Bio tool,
- exact calculations of low - energy houses [10], [11],
- analysis of influence of salts and contamination of the cavity system in a material on water transport,
- etc.

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CONSTRUCTION OF HIGH-SPEED TRACKS

The current situation and conditions of construction of high speed tracks (HST) in the Slovak Republic and the comparison with the situation abroad. The speed of train sets and the track quality for high speed trains. The dynamics of railway running. The speeds of the HST trains are limited by the respective track state. The tilting train set wagons - increasing the new levels of speeds in railway curves. The time comparison of the high speed trains to air and road transport "from city centre to city centre". The required conditions and parameters of construction of high speed tracks up to $V_{max} = 200\text{–}240$ *km.h*$^{-1}$ *within the track modernizations.*

1. Introduction

The prospective solution of concentrated traffic, which is considered in the world as well as in the European Union, is faster and comfortable movement of high-speed trains on railway tracks. Quality eco-friendly railways will be competitive to roads and highways that pollute the environment at an increasing rate. At medium distance transport the railways may also compete to air transportation systems, by the system known as "from city center to city center" of connected cities. Of course, we speak about the high-speed trains for passengers and freight transport. The other possibility is a railway transport system with connections to these high-speed tracks, as it is supposed to be adopted before the emission transport that will have limited natural resources for fuel production.

In this paper we exclusively address to high-speed trains and the need of track construction to secure the utilization of high speeds of respective train sets. At present, all lines, (foreign speed-tracks), which are used by the trains that run faster than $V = 200$ km.h^{-1}, are considered high-speed tracks (HST). The traction vehicles with their sets can run at higher speed $V = 300$ km.h^{-1}, possibly even higher, but they are limited by the current track state at $V = 200\text{–}240$ km.h^{-1}. This can be demonstrated by the experience of foreign railways.

Concerning the new track modernization, in Slovakia this is not an issue in question at all because by the modernization of tracks only the speed $V_{max} = 160$ km.h^{-1} is considered. The only possibility for Slovakia is the construction of high-speed track in the length of 1500 km of Paris – Bratislava line. The complete putting into operation is scheduled for 2020 (Paris – Strasbourg – Stuttgart – Munich – Vienna – Bratislava). If we want to use these train units in our country, it is necessary to prepare the new parameters of existing lines and turnout layouts of railway stations on associated tracks, otherwise Bratislava would remain a terminal station. And vice versa, besides their utilization in Slovakia our train sets could be also used at high speeds on these new HST tracks outside Slovakia.

The trains are also limited by the prescribed maximum allowed speed V_{max} according to the rules and standards in the respective country or by the maximum speed in particular track sections. The stagnation of research and development should be prevented and therefore it is necessary to create new research challenges and gain experience abroad, including new railroad materials.

2. Basic conditions of the HST lines

The fastest trains on the line need certain preferential right of way before the slower types of trains (EC, IC, R, Ex, Os, Pn, Mn etc., for example at $V \leq 160$ km.h^{-1}). At the same time these slower trains present certain barriers for HST trains. They need to be "hidden" in the railway station track area during HST train passing. This procedure is a standard in the countries, where the already existing HST tracks are used and modernized.

Alternatively, the HST track can be built on a separate railway body, especially for trains running at speed $V = 300$ km.h^{-1} and higher. In the case of high-speed tracks it would not be economical to use it for high-speed trains only. Already in the preparation of high-speed tracks the exploration of specific conditions and traffic carrying capacity of tracks using different types of train vehicles (with the necessary reserve for a future capacity) is needed.

The most important components are two basic ones. The traction vehicles (*hv*) with the sets of transported vehicles, which are able to run at the required $V_{max}{}^{hv}$ speed. On the other hand the

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railway track which has to ensure the transit safety of these sets at V_{max}^{i} in particular track sections (i). Both speeds are related to the maximum permissible V_{max} speed on the track which vary by individual standard criteria depending on a particular country. From the point of view of track geometry, in the track sections there is necessary to expand the curve radiuses in the R_{max} sections within the reconstruction (including quality geometric transitions and vertical spirals [3]), because the HST trains would be slowed down by these small radiuses.

The turnout layouts are other speed-limiting elements, i.e. connections and branching in railway stations (mainly in large urban areas), that the trains run through, and the speed V_{max}^{zh} is also limited by the turnouts structures (zh).

3. Track structures for high speeds

The trains have to run on time and therefore it is necessary to build high quality railway corridors which will be sustainable for high speed V_{max} with its geometric spatial position within the criteria of critical horizontal and vertical deviations. The stability of the geometrical position is strictly required to avoid unnecessary rails repairs of tracks and to prevent the tamping machine becoming another barrier for speed-trains on the track.

The stable track geometry is ensured by a durable track grid that uses reinforced concrete sleepers which transmit force load resulting from the dynamic behavior of driving trains into the lower layers of railway subgrade [1]. The ideal solution is building solid trackbed constructed from concrete and modern reinforcing materials that have good force transmission effects and also prevent the noise emissions releasing into the environment. An integral part is a flexible spring fastening system (Pandrol, Vossloh, etc.) of rails on the sleepers within the track grid [5], or their installation into a solid trackbed.

Finally, we must not forget the quality and stability of sleeper ballast and subgrade that in the case of any instability would deform the superstructure as well as the track grid and the collapse of track geometry position would become a real threat.

The track geometry is necessary to be controlled in the prescribed time intervals by surveying groups and by the track measuring machines, while the horizontal and vertical conditions are maintained in the state required by the project documentation. The quality tracks generally have minimum deviations from the designed axis in a long-time perspective. In our paper we consider the speed zones at RP4 V_{max} = 160–220 km.h^{-1} and RP5 at V_{max} = 220–300 km.h^{-1} in accordance with the upcoming new STN 73 6360 [6], as the CSN 73 6360-1 [7] CSN 73 6360-2 [8] in the Czech Republic. The criteria are applied from European standards EN [9] due to the approximation and harmonization of regulations and standards within the common European area.

High speed turnouts: for maximum speed the straight direction (s) of turnout (t) is required, in the of case of direction change it is necessary to consider the $V_{max}^{t,R}$ speed of the radius (R) as in Table 1 (the transformed turnouts have two curves). The high-speed turnouts are designed for speeds in a straight line $V_{max}^{t,s} \leq$ $\leq$ 300 km.h^{-1}. In the case of higher speeds specific turnout structures have be manufactured in accordance with the train set load with the fluent progress of curvature (e.g. clothoid).

Turnouts of high-speed tracks – HST Table 1

Speed into turnout branches $V_{max}^{t,R}$ [km.h^{-1}]	Turnout	Structural length [m]	Central angle [°]
110	1:21.5-1600	74.338	2.3671
120	1:22-1800	81.776	2.6025
130	1:26.5-2500	94.306	2.1611
140	4500/2800*/straight	120.959	1.8977
160	6000/4000*/ straight	142.800	1.5931

There are two different views of these turnouts. The high-speed track passes only in a straight line (s), but other trains also run into branches at $V_{max}^{t,s}$ = 50 to 110 km.h^{-1} for turnout as from 1:26.5-2500 to 1:12-500. The second view is that the trains into branches require $V_{max}^{t,R}$ = 110 to 160 km.h^{-1} and higher, see Tab. 1, [2].

At higher speeds for branches $V_{max}^{t,R} \geq$ 130 km.h^{-1}, a clothoid spiral is designed (EU and outside EU railways), otherwise at lower speeds the circular curves are produced. In turnouts of Table 1, the clothoid progress between radiuses of 4500/2800 m and 6000/4000 m into branches at their speeds of 140 and 160 km.h^{-1} is changed.

For the curves with transitions of high-speed lines we can already design clothoid spirals instead of cubic parabolas (updated equation with correction factor γ), which are geometrically of a better quality. Of course, as well as the Bloss spiral and other spirals with the fluent curvature [3].

4. Driving at high speed on a curve

The stable position of vehicles and elimination of the adverse effects of centrifugal forces are necessary to be ensured during the high-speed trains passing a curve at a high speed. By the speed increasing at a particular maximum elevation of rails we are limited by the critical V_{max}^{R} speed in particular radius (R) and superelevation (D). We can increase the speed in a given track section taking following measures:

1. reduction of the weight of the sets (mainly passenger vehicles),
2. lower center of gravity by the mass distribution of sets and materials,
3. using only sets with tilting body of wagon with $\Delta\alpha$ = 0° to 8° (Fig. 1),
4. sets as a single unit (aerodynamic resistance).

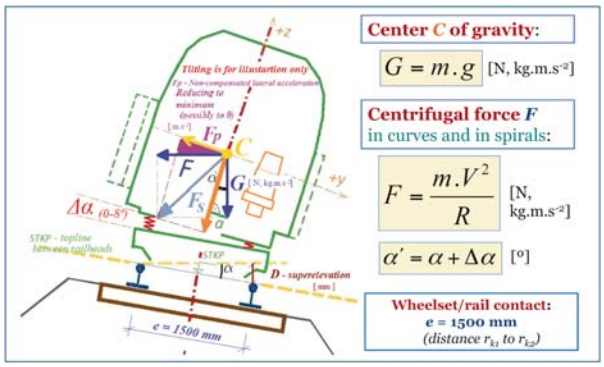

Fig. 1 Forces influence - tilting railway wagons

Besides the stable position we have to keep in mind the comfort of passengers and also avoiding damage to transported goods. Of course, the train sets must overcome all the active (the primary energy source driving the vehicle and all transfers from engine to a point on the rail) and passive driving (track and vehicles) resistances - the dynamics of rail driving.

If you choose to compare the high-speed trains that have fulfilled all of the conditions above and the conventional trains (EC, IC, R, EX, Os, Mn train sets etc.) in the same curve, the high-speed trains can move at a speed of 1/4 to 1/3 higher. To demonstrate this, in our example $V_{max}{}^{R} = 180–240$ km.h^{-1} for HST train sets and for others $V_{max}{}^{R} = 120–160$ km.h^{-1}, where by the centrifugal forces (F) different speeds developed. An important fact is the aerodynamic shape factor of the first front drive wagon, including the mutual connections of individual wagons in the set with minimal added aerodynamic resistance of each carriage.

Small radiuses tend to slow the train sets down, therefore it is necessary to ensure a minimum radius of curvature R_{min} for the required speed $V_{max}{}^{R}$ by the designers. Nowadays it is necessary to modernize railway lines and use this modernization to increase the speeds (if it is not possible to construct separate track corridors). The high-speed trains may also be limited by the maximum speed allowed in a particular country, as in some federal states within the U.S.A., $V_{max} = 240$ km.h^{-1} is the speed limit. It usually is the speed in straight track sections. In the curves and spirals it will decrease to lower values of speed $V_{max}{}^{R} = 160–190$ km.h^{-1} using the sophisticated modernized tracks.

5. Railway transport from "city center to city center"

The speed and high-speed trains, according to various studies, can compete with air transport at distances between cities of 600–900 km. The passengers spend equal time in comfortable transport vehicles at the same distance and they directly board the train with their luggage and will get off on platform in the next city center. The train sets usually stop at city centers of two or three other cities. We can mention the Washington – Philadelphia – New York – Boston line as a classic example of a speed-track, there are many more similar examples. As rather uncomfortable there could be seen the fact that airports are principally placed outside of city centers at a distance of 20–40 km.

The location of nodal points and end points of high-speed railway stations will considerably increase appreciation of this area and will also increase its attractiveness (growth of real estate construction and miscellaneous services, etc.). In the surroundings of these stations there will be created a locality with higher added value, the unused parts of municipal plans might possibly be evaluated and they can be recovered within the urban planning, because it is a usual course by concentrating the traffic into the respective transport junction of HST trains.

The study of follow-up and associated transport has to be processed for these high-speed trains, including urban railways, and underground transport systems as dynamically developing environment. The railway transport has a great future in the city centers, as it can solve the environmental and traffic situation after the exhaustion of fossil fuels of other competitive transport systems. In principle, we can speak about railways as a perspective, comfortable and rapid transport, as opposed to slow streams of cars on the roads and highways. Using the railway transport we experience no stress compared with driving on the roads with different traps, because the trains will bring you comfortably to your destination while you can dedicate your time to work or simply relax.

6. Conclusion

The staff of the Department of the Railway Engineering and Management of Civil Engineering of the University of Zilina (http://svf.uniza.sk/kzsth) has dealt with the design and operational criteria of standards and rules of high-speed (HST) tracks for a long time. We have gained valuable experience from foreign designers in the field of railway engineering, as the Slovak Republic is only at the beginning of perspective practical implementation with a maximum modernization up to the $V_{max} = 160$ km.h^{-1} from the current modernization. In the coming years the construction of rapid railway transit will be in operation at the intended speed $V_{max} = 300$ km.h^{-1} on the track from Paris to Bratislava and it will give us the opportunity of using HST trains in Slovakia. In the future there is pressure to build these lines through the territory of the Slovak Republic in the direction of the main European railway corridors.

Although the manufactured high-speed train sets are already available, there is a recent need to rebuild the track for a specific track speed with the required parameters. Alternatively, there is a possibility of section construction, where in some track sections the $V_{max} = 200–240$ km.h^{-1} will be used and in the limited track sections we can keep the current $V = 160$ km.h^{-1} speed. The prerequisites also are the financial resources, which can be obtained e.g. from the European Union funds for developing the ecological transport infrastructure.

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THE COHESION OR DILATION EFFECT ON THE SHEAR STRENGTH OF GRANITIC RESIDUAL SOIL

The paper reports laboratory investigations carried out in granitic residual soil from Covilha, to evaluate the stress-strain-dilatancy behaviour to provide a new model. Some soil tests are intended only to classify soil into broad groups. Other tests are done to examine the mechanical behaviour of soils and particularly to investigate their strength and deformation during loading. Drained and undrained triaxial tests were performed to study soil fabric effects on the mechanical behaviour of a granitic residual soil. It was revealed that the dilatancy of the saturated soil contributes to shear stress and strength at lower confining pressures. The cohesion is apparent for small stress and we need to introduce the evaluation of volumetric strain to understand the effect of the dilatancy in the peak strength.

Keywords *Dilatancy • Laboratory Tests • Granitic Residual Soil • Shear Strength*

1. Introduction

The resulting soil, before the transport has occurred, is named residual soil. Its features are similar to decomposed rocks due to the succeeded structure and fabric, which depends on the alteration degree that occurred. It has specific mechanical properties, depending on the alteration degree, chemical ratio, structure and void ratio. Burland [1] defined the term "structure" of a natural soil as consisting of the spatial arrangement of soil particles and inter-particle contacts named fabric, and "bonding" between particles, which can be progressively destroyed during plastic straining, giving place for the term "destructuration". When the granitic residual soil from Covilha is destructurated he has mechanical behavior similar to a granular soil.

Granular materials with different densities respond in different ways to applied shear stress. At low confining pressures, loose sand will compress and dense sand will dilate during the shear. In the present paper it was found that the granitic residual soil at low confining pressures that dilate exhibits, stable its behaviour until the failure surface has been reached. The dilation nature of structured samples decreases with increasing confining pressures, and only contractive behaviour is observed at high confining pressures, like a dense sand mechanical behaviour. The effect of initial soil fabric, which plays an important role at lower confining pressures, is not significant at high pressures where the fabric is controlled by the contraction and the crushing of the grain structure. Structured samples tested under drained shear show a transition from brittle/dilatants behaviour to a ductile/compressive response, as confining stress increases. However, the effects of bonding on stress-strain-volumetric response of natural and artificially cemented geomaterials revealed that the dilation of the intact soil is inhibited by presence of cement component [2] [3].

The results of a study on the behaviour of granitic residual soil from Covilha at low and high effective confining pressures (25 to 400 kPa) under drained (CD) and undrained (CU) conditions in triaxial compression are presented here. The experimental results show consistent patterns of stress-dilatancy behaviour in both tests. The effect of dilatancy in peak strength appears like apparent cohesion and these concepts are found in critical state observation onto planes deviator stress versus effective medium stress (q:p') and specific void index versus effective medium stress (v:$ln\ p'$). The critical state line is unique in the q: p' space, dependent on the frictional effect on shear strength. In the v: $ln\ p'$ space the average isotropic state line (ISL) does not seem to be parallel to the critical state line determined from CU and CD triaxial tests but these lines tend to converge at higher confinement stresses. This behaviour is linked to evaluation of the dilatation effects on strength of this soil, implying the evaluation of volumetric deformations and a stress-dilatancy analysis.

2. Soil Type and Sample Preparation

All triaxial compression tests in the experimental program were performed on cylindrical samples of residual soil. The soil used in this study was a granitic residual soil taken from a deposit located in Covilha, Portugal. The in situ water content of the soil has 17%. The soil tended to form aggregates larger than 20 mm in diameter

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in the natural state. The classification tests on the soil were conducted in accordance with the procedures described in British Standards Institution [4]. The results are summarized in Table 1.

Identification and physical parameters of the granitic residual soil in Covilha — Table 1

Index test	Granitic residual soil
Grain size distribution(1)	
Percentage of Gravel	20–38
Percentage of Sand	50–60
Percentage of Silt	9–14
Percentage of Clay	3–6
Effective size, D_{10} (mm)	0.007–0.04
Coefficient of Uniformity, C_U (-)	47.5–200
Coefficient of Curvature, C_C (-)	1.2–4.1
Specific gravity, G_s (-)	2.67
(1) Desflocculating used: hexametaphosfate	

The soil comprises 20 to 38% gravel, 50–60% sand, 9–14% silt, and 3–6% clay, which can be described as silty sand with gravel. The natural granitic residual soil belongs to the SW-SM group with gravel [5], with normal or low clayey activity, denouncing the presence of kaolinite with less expansive clay. The classification of soil may be done according to the Unified Classification System if we take precautions or make the necessary alterations on the methodology of the samples preparation and if this system is used together with the geological knowledge of the soils. The granulometric features of these soils have a slight importance, contrary to the sedimentary soils, concerning its mechanical behaviour to an interlocking fabric and degree of weathering [6].

The triaxial remoulded samples 100 mm in diameter and 200 mm in height were prepared by wet tamping method, according to standard proctor compaction procedures. The samples were compacted in a split mould in order to minimize its disturbance, using water contents and dry densities corresponding to the proctor maximum. The samples were compacted with water contents (w) of 13% in two groups of samples: one corresponded to the specific volume ($v = 1 + e$) ranging from 1.397 to 1.417 (group: A-nc), and the other group (A-sc) corresponded to the specific volume ranging from 1.601 to 1.621. Probably, we have the loose soil structure formed by the compaction method used in these samples.

Undisturbed samples 100 mm in diameter and 200 mm in height were taken by driving thin-walled samplers in the residual soil. The samples were extruded at steady speed using a mechanical device with plunger of almost the same diameter as the inside sampler diameter applied to the bottom of the sample, in order to avoid disturbance and distortion of the soil. The specific volumes range from 1.409 to 1.556 and the degree of saturation from 50% to 68%. Fig. 1 shows the specific volume versus degree of saturation of structured and remoulded samples.

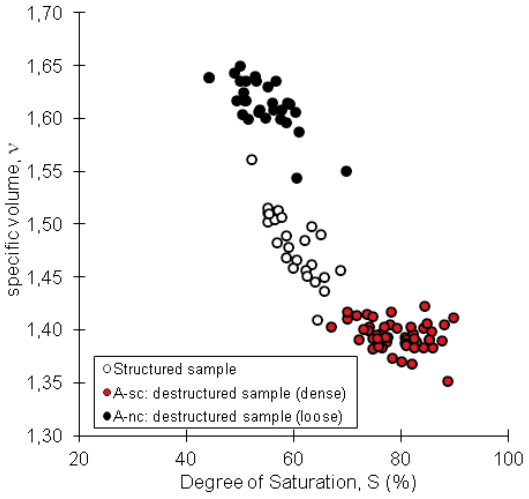


Fig. 1 Specific volume versus degree of saturation of structured and remoulded samples

The results from Fig. 1 clearly indicate high anisotropy of the granitic residual soil.

3. Mechanical Behaviour of Granitic Residual Soil

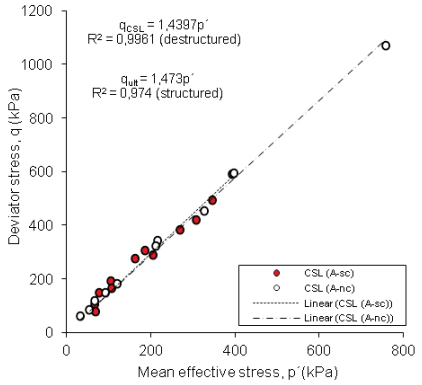
3.1 The Intrinsic Behaviour

It is important to define the intrinsic mechanical behaviour of the soil which is obtained from the tests made on destructured or remoulded samples (group A-nc and group A-sc). The intrinsic behaviour is defined for the state on which the initial physical and structural properties of the soil have no influence on its mechanical behaviour. It's the critical state. On granular soils we need large volumetric compressive strains, where it is possible to get the rate of change as null at constant volume of normal and shear stress.

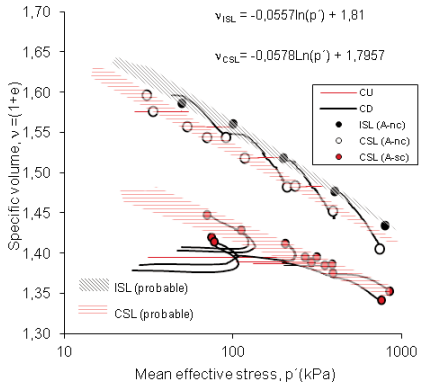
The projection of critical state line (CSL) onto $q{:}p'$ plane may be described by: $q = Mp'$, where M (*capital mu*) indicates the gradient of critical state line . The projection of critical state line onto $v{:}p'$ plane may be described by: $v = \Gamma - \lambda \ ln \ p'$, where Γ (*capital gamma*) is defined as the value of specific volume (v) corresponding to $p' = 1.0$ kPa on the critical state line in the $v{:}\ lnp'$ space and λ is the slope of normal consolidation line (negative).

We have now considered separately the failure of samples which were initially isotropically compressed and then loaded in drained and undrained triaxial compression tests. It is striking that the lines of failure points in Fig. 2a appear to be similar for two families of tests and it is instructive to compare these directly. The

average isotropic state line (ISL) in Fig. 2b does not seem to be parallel to the critical state line determined from CU and CD shearing tests and these two lines tend to converge at higher stresses, implying that the state parameter (ψ), proposed by Been et al. [7] for quantitatively measuring the dilatancy of soil, would probably decrease as the stress level increases.



a)



b)

Fig. 2 Failure points for drained and undrained tests on granitic residual soil (loose and dense samples): a) q:p′ space; b) v: lnp′ space

He also defined the intrinsic compression line (ICL) as the one-dimensional consolidation slope of granitic residual soil that had been reconstituted from a liquid limit (w_L = 30%). By reconstituting the sample at high initial water content, the soil ideally loses all memory related to the soil structure [8]. Fig. 3 presents the "unique" ICL when the data were normalized by Burland (1990) parameter (I_v) calculated by the following equation,

$$I_v = \frac{e - e^*_{100}}{e^*_{100} - e^*_{1000}} = \frac{e - e^*_{100}}{c^*} \qquad (1)$$

which is based on the constants of intrinsic compressibility, e^*_{100} and e^*_{1000} (void ratio corresponding to effective vertical stress of

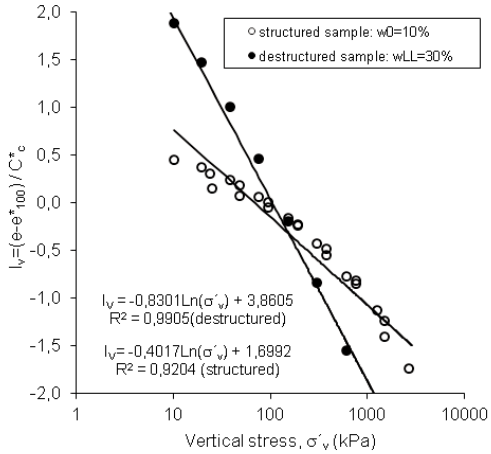


Fig. 3 Structured and destructured samples normalized with Burland's void index parameter [1]

σ'_v = 100 kPa – yield stress – and σ'_v = 1000 kPa), and $C^*_c = e^*_{100} - e^*_{1000}$. Compared with a structured sample of granitic residual soil, it may, in fact, not be a truly intrinsic parameter of soil, but it is dependent on the sample fabric, alteration degree and preparation.

The measured high compressibility was probably due to the presence of crushable feldspar in the soil and the soil structure. The mineralogy and the fabric and, subsequently, the corresponding soil properties, may influence the degree to which the initial water content affects the compression curve of a structured soil and the intrinsic compressibility. This is responsible for a different CSL in *v:lnp′* space when the samples are sheared.

3.2 Stress Behaviour and Peak Strengths

Isotropic consolidated undrained and drained triaxial tests were performed on structured soils with the objective to get a complete understanding of the stress-strain-strength-dilatancy behaviour. The saturation of each sample was ensured by water flow followed by application of back-pressure. Radial and base drainage were adopted and 98% consolidation was obtained in less than 9 minutes. The rates of shearing adopted were 0.04 and 0.01 mm/min, respectively, for undrained and drained tests.

As it is shown in Figs. 4a and b, the stress-strain results of the drained test on the structured sample, the shear stress exhibits a peak in its q: ε_a (deviator stress: axial strain) curve, and, therefore, q decreases and is still decreasing at the end of the test. The sample contracts slightly initially, but then expands strongly until the end of the test on the low confining pressure. The shapes of q: ε_a curves for the undrained test are similar, though the values of q at failure are very different. The difference in pore water pressures at failure is the major cause of the large difference in the observed shear strength. As shown in Fig. 4a, the most stress-strain curves from undrained tests display peak deviator stresses and tests at

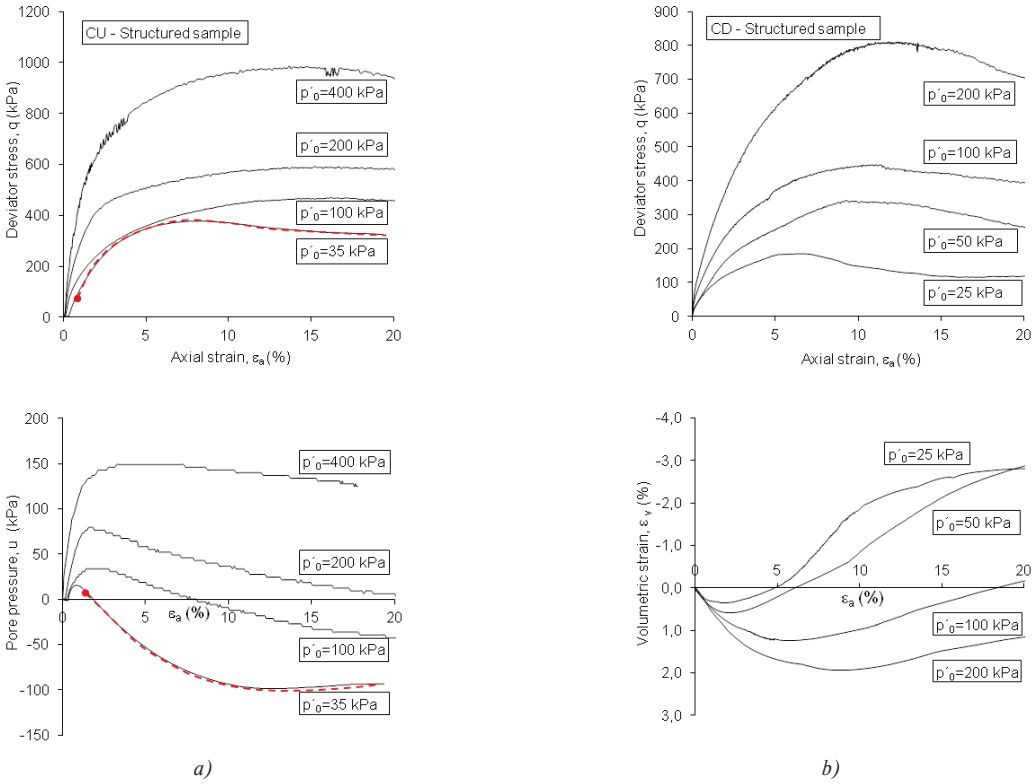


Fig. 4 Structured samples: a) stress-strain relationship; b) relationship between volumetric strain, excess pore-water pressure and axial strain

low confining stresses display negative pore pressures. The loss of shear strength was accomplished with an increase in the pore water pressure. In terms of energy it is suggested that the total work done by the stresses at the boundary of an element is partially dissipated in friction and partly in disrupting the structure of the soil.

This is a typical behaviour of sands. This pattern of behaviour is similar to that observed for clay, for overconsolidated samples of clay expand during shear and generate negative pore water pressures. This behaviour in structured soil is dependent on consolidation stress and variable bonding.

The effective deviator stress at failure in loose and dense remoulded samples for high confining stress is substantially larger than that for low confining stress; the ratios of principal stresses σ'_1/σ'_3 are, however, almost the same for both cases. In structured samples, as shown in Figs. 5a and b, the ratios of σ'_1/σ'_3 are not the same for both cases. For $p'_0 = 25$ kPa in CD test or $p'_0 = 35$ kPa in CU test, the ratios increased due to the dilation effect, having the peak about 2 and 4 % of axial strain and decreasing to a simple frictional effect. For high confining stress or during plastic straining inter-particle contacts and "bonding" between particles, which can be progressively destroyed and the strength is dependent on a simple frictional effect.

However, in structured samples, if the peak strength is frictional, and the gross yield (GY) represents the onset of major bond degradation, the soil must, therefore, undergo substantial destructuration between the gross yield and the peak, as shown in Figs. 5a and b.

3.3 The Effect of Dilation on Granitic Residual Soil (Stress-Dilatancy Behaviour)

We have discussed the maximum possible value of (σ'_1/σ'_3) or (q/p') that a residual soil may resist at different states. We may now consider a drained test on granitic residual soil. The stress-dilatancy behaviour of granular soils plays a very important role on strength control; together with connections between particles there is the fabric effect, both leading the mechanical behaviour. In destructured material the peak strength generally coincides with maximum rate of dilation. In bonded materials (structured) the samples show dilation and brittleness at low confining stress, peak does not coincide with maximum rate of dilation. Natural and artificially cemented geomaterials revealed that dilation of the intact soil is inhibited by presence of cement components [9]. Fig. 6 shows the stress-strain relationship of a low confining pressure, $p'_0 = 25$ kPa, in a drained triaxial test.

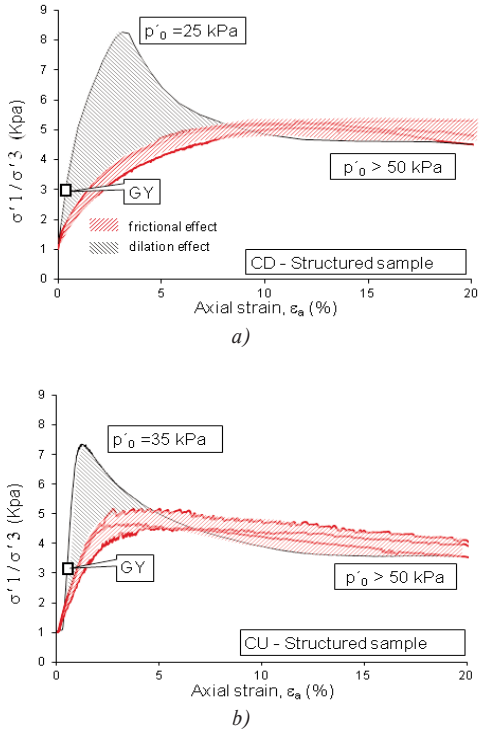


Fig. 5 Effect of initial stress ratio on ductility in structured samples: a) CD tests; b) CU tests

For the peak stress an increment of horizontal displacement δu in a simple shear deformation, the net work transferred in to the sample during the increment and the frictional work is,

$$T'_{yx}A\delta_h - \sigma'_y \; A\delta_v = \mu\sigma'_y \; A\delta_h \Leftrightarrow$$
$$\frac{T'_{yx}}{\sigma'_y} = \mu + \left(\frac{\delta_v}{\delta_h}\right) \qquad (1)$$

We suppose that the coefficient of friction between the contacting faces is μ. Now it is temping to generalize where the invariants q (deviator stress) and p' (mean effective stress) are comparable with τ (shear stress) and σ' (principal effective stress), respectively [10], and rewrite in terms of the equivalent invariant parameters this stress-dilatancy relationship:

$$\frac{q}{p'} = M + \frac{\delta\varepsilon_v}{\delta\varepsilon_h} \qquad (2)$$

where

$$\eta = \frac{q}{p'}; M = \frac{6\sin\varphi}{3-\sin\varphi}; \psi = \frac{\delta\varepsilon_v}{\delta\varepsilon_h}$$

Each drained triaxial test analyzed gives the same unique straight-line relationship between the rate of dilation ($\delta\varepsilon_v/\delta\varepsilon_h$) and the stress ratio $\eta = q/p'$, which can be calculated using Eq. 2. The stress-dilatancy evaluation was made with projection of maximum stress coefficients (η_{max}) in function of maximum dilation (ψ_{max}) for the destructured sample and the structured sample, as illustrated for granitic residual soil in Fig. 7. As the tests were terminated shortly after the peak, critical states cannot be identified from the stress-strain data, and a stress-dilatancy analyses can then be useful in the understanding of the underlying behaviour of the soil.

The internal frictional angle (ϕ_p) of peak strengths increase is associated with a dilatancy increase. When $\psi = 0$ the soil mechanical behaviour is in CSL. The unique relationship in Fig. 7 indicates that the shearing behaviour is purely frictional so that the peak strengths are solely with dilation; the intercepts represents the CSL gradient, M and corresponds to a critical state friction angle, ϕ'_{cs} of 36° to destructured sample and ϕ'_{cs} of 38° to structured sample. These are unusual high values for sand that is predominately quartz, but this value is no constant over a very wide range of pressures and it may be related to the relatively high propor-

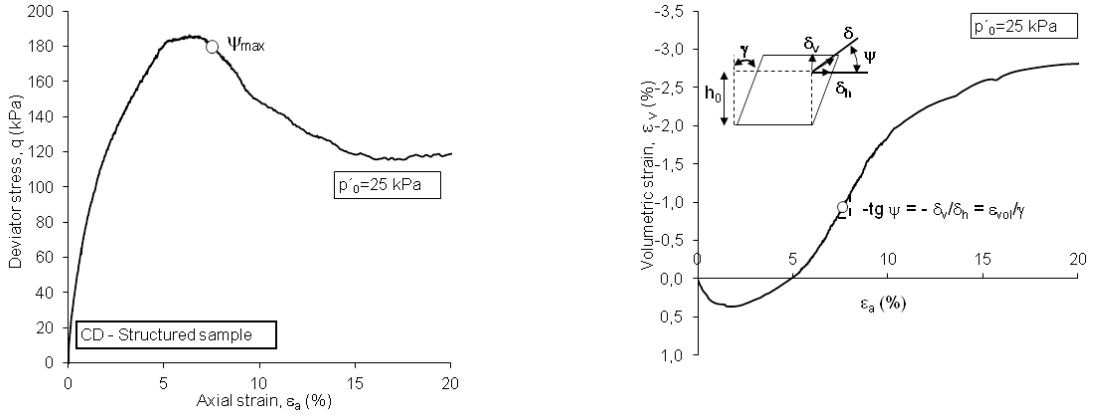


Fig. 6 Stress-strain relationship

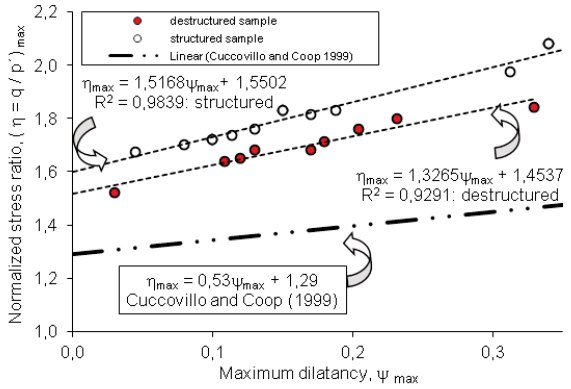


Fig. 7 Stress-dilatancy data for destructured dense sample, structured sample of residual granitic residual soil and the same relationship obtained from Cuccovillo and Coop (1999)

tions of other minerals present and the gradual destructuration of the fabric and bonding.

The failure envelopes obtained in drained triaxial shear tests is shown in Fig. 8. Initially, the sample will compress slightly and then expand as the test proceeds and the stress paths move up towards the critical state line. Again, it is clear that the peak strength results from dilation as there is no evidence of a true cohesion interception.

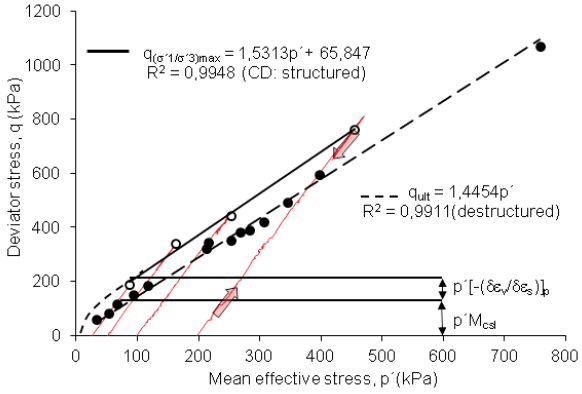


Fig. 8 Effective stress path for drained tests on saturated granitic residual soil: failures envelopes for $(\sigma'_1/\sigma'_3)_{max}$ and ultimate and intrinsically criterion of rupture

The peak strength is the result of two effects: a) the frictional effect, $\sigma' tan\ \phi'$ or $(q/p')p = M$ and b) the dilatancy effect, $\sigma'[-(\delta\varepsilon_v/\delta\gamma)]_p$ or $p'[-(\delta\varepsilon_v/\delta\gamma)]_p$. After the peak, the soil strain softens, apparently following a straight line frictional trend on the stress-dilatancy plot, but as the stress ratio reduces, strain localization occurs so that the rate of dilation reduces more rapidly than the stress ratio, bringing the path inside the expected frictional relationship.

Fig. 9 shows a typical effective stress path of the undrained test in $q{:}p'$ stress plane. The volumetric behaviour of the sample can be indirectly reflected from the shape of the effective stress paths. The variation of pore water pressure in loose sand at failure is different from that of structured samples.

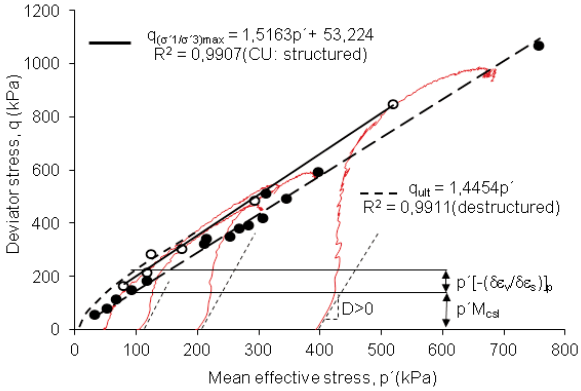


Fig. 9 Effective stress path for undrained tests on saturated granitic residual soil: failures envelopes for $(\sigma'_1/\sigma'_3)_{max}$ and ultimate and intrinsical criterion of rupture

The loose sample has a positive pore water pressure at failure, while in structured samples this is greater and negative. In structured samples the negative variation in pore water pressure produce an increment in effective stress and the effective stress path moves towards the right-hand side (D>0). This is an indication of the tendency to dilate.

4. Conclusion

The present investigation was performed to conduct a thorough examination of the effect of dilatancy on the drained and undrained stress – strain, volume change or pore pressure, and strength behaviour of intact granitic residual soil. The residual granitic soil contains some quantity of fines and its mechanical behaviour in drained and undrained triaxial shear tests is similar to that of sands for the same relative density and confinement stress.

However the classical models of soil mechanics cannot be used to describe the mechanical behaviour of residual soil, as the strength of the structure is independent of density. Based on the intrinsic compressibility test results presented in this study it appears that the value of e^*_{100} of the soil is dependent on the structure and initial water content of the soil sample. The intrinsic parameter I_v may not be a true intrinsic soil property because the strength of the soil depends on the gradual destructuration of the fabric and bonding when the loading increases.

The effect of initial structure on the volumetric space dilatancy is most pronounced in the low pressure regime and this con-

tributes to soil strength. Again, it is clear that the peak strength results from dilation as there is no evidence of a true cohesion interception. The linear regression is not a necessarily the best fit. The relation stress-dilatancy of these soils plays a very important role in behaviour control; together with connections between particles there is a fabric effect, both ensuing to the mechanical behaviour. Then the Mohr Coulomb failure criterion is not availed in the simplest space of stresses because it is necessary to use the space of deformations together. The natural structure of bonded soils has dominant effect on their mechanical response since the apparent cohesion/dilation component can dominate soil shear strength at engineering applications involving low stress levels. The interpretation of peak strength behaviour of this soil needs the combination: $\phi_{peak} = \phi_{critical\ soil} + \psi$.

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Martin Hrinko – Katerina Orlikova *

TOXIC PROPERTIES OF PLASTICS IN FIRE AND THEIR IMPACT ON THE ENVIRONMENT AND HUMAN HEALTH

The article describes and analyses toxic substances produced during a combustion of plastics which affect human health. Accidents and emergencies resulting from the combustion of plastic materials occur very often during the industrial production and technological processes. The authors illustrate this fact using the most recent example – the fire in the manufacturing and logistics premises in Chropyne, the Czech Republic, during which the professional as well as volunteer firefighters and the specialized fire rescue service units were employed.

Key words: *toxicity, fire, safety and fire protection.*

1. Introduction

In the environment, in industry, motorism, aviation and in many other key industries a wide range of substances with various chemical properties is used. These, as a result of a chemical reaction caused by the fire, are transformed into tens or hundreds of different chemical substances with new and in most cases even more dangerous chemical properties. It is to be noted that the toxic properties of the newly produced substances depend also on the type of extinguishing agent used. Saving human lives (including the firefighters and other personnel) is the main goal during firefighting. The dangerous factors during firefighting are:

- elevated ambient temperature,
- excessive formation of smoke,
- decrease in oxygen content in the air and
- toxic products of fire.

Elevated ambient temperature makes the firefighters' work difficult, provokes defatigation and dehydration. Inhalation of hot products of combustion damages the airways, decreases blood pressure and may result in failure of blood circulation, pulmonary edema or even in death. *Formation of smoke* reduces visibility in the seat of fire and decreases the sense of orientation, mostly in an unknown area, but also in a familiar area. A smoke is in fact an aerosol, in which the dispersed phase is formed by carbon, dust or tar particles and other products of combustion. Highly toxic substances often condensate on the surfaces of the dispersed particles. Nowadays, it is widely known that smoke inhalation or contact of smoke with the skin represent a big danger. A conflagration needs *oxygen* in order to burn. Sometimes, oxygen is contained in the molecules of a combustible matter, but in most cases, it comes from the air. 23% of the weight of the air (and 21% of its volume) is made up of oxygen. It is the same amount which a human being needs to survive. During a fire, particularly in enclosed places, the amount of oxygen in the air decreases, which affects the performance of the firefighters and the lives of other people present in the seat of fire. The influence of the amount of oxygen in the air on human body is depicted in Table 1.

The influence of the amount of oxygen in the air on human body [5]. Table 1.

The amount of oxygen in the air [%]	Symptoms of a lack of oxygen
21	Normal course of life, no difficulties.
17	Hyperventilation – effort to compensate for the oxygen deficiency. Impaired coordination of muscle movements.
12	Headache, rapid tiredness, dizziness.
9	Unconsciousness.
6	Death (after a few minutes). Asphyxia and heart failure.

A conflagration also produces a wide range of *toxic substances.* Their properties and their quantity depend on the original properties of the combustible matter. A variety of substances with different properties is produced naturally as well as industrially. During a fire, these substances react and, as a result, hundreds of new substances with new, and in most cases, more dangerous properties are created. Moreover, even firefighting can encourage creation of toxic substances.

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2. Conflagration and the resulting toxicants in dependence on the course of the fire and the nature of the combustible matter [4,5]

This chapter describes the origin, properties and the influence of those toxicants, which are most frequently produced during a conflagration. More specifically, the chapter describes the toxicity of the following compounds:

- carbon compounds (namely carbon dioxide, carbon monoxide and various hydrocarbons contained in the table of toxicity),
- sulphur compounds (namely carbon disulphide, hydrogen sulphide and sulphur dioxide),
- nitrogen compounds (namely nitrogen oxides, ammonia, cyanide compounds and amines) and
- phosphorus compounds (the chapter describes the properties of phosphorus oxides).

A table describing the immediate lethal doses of each of the toxicants most frequently produced by conflagration represents an important part of this chapter. As it has already been stated, during a fire, numerous new compounds are created (as the intermediate products or as the end products of combustion). The intermediate products are, for example, high-molecular hydrocarbons (often aromatic or polyaromatic hydrocarbons) in the form of an oxygen compound (such as aldehydes, ketones, esters, high-molecular alcohols, etc.). Some nitrogen compounds which can be included in combustion products are cyanide compounds, various types of highly toxic amines, nitrogen oxides or ammonia. The oxides of combustible elements (contained in a combustible matter) are the end products of combustion. Most often, these are oxides of carbon, sulphur, phosphorus and other chemical elements. Their toxic properties can be found in the the following text as well as in the table below.

2.1. Toxic properties of carbon compounds produced by a fire

The carbon compounds produced by a fire are carbon dioxide CO_2, carbon monoxide CO and, depending on the type of the fire and its temperature, hydrocarbons (such as carbon disulphide CS_2 – a combustible and an explosive substance).

Carbon dioxide CO_2 – is a product of a complete combustion of carbonaceous matters. It is a colourless gas with a slight acidic odor, which irritates the pituitary membrane. It is easily liquefiable and at 1 atm it changes to a solid commonly called “dry ice” or “dry snow”. Dry ice has the temperature of –78.48 °C and if it comes into a direct contact with skin, it causes serious burns. Carbon dioxide ís heavier than the air. The weight of 1 litre of CO_2 is 1.97 g (at 1 atm and 0 °C). Its density in relation to the density of the air is 1.52. Therefore, it accumulates near the floor, in basements, pits, wells, etc. It dissolves in water. The dissolution is accompanied by formation of carbonic acid, which has corrosive effects. Carbon dioxide is non-flammable, but will support the combustion of metals. It reacts with metals, forming flammable, explosive and highly toxic carbon monoxide:

for example:

$$\mathbf{Mg + CO_2 = MgO + CO}$$

Carbon dioxide also reacts with carbon (a non-metallic element):

$$\mathbf{C + CO_2 = 2\ CO}$$

The chemical equilibrium in the reaction above depends on the temperature of the fire and on an eventual presence of catalysts. Carbon dioxide is not a toxic gas (it does not alter cellular functions), but it is unbreathable. It is an end product of metabolism of organisms. As for human beings, the alveolar air contains 5–6% of CO_2, the exhaled air contains approximately 3.5% of CO_2. If inhaled, its irritating effects are negligible, except for its principal effect, which is difficulty in breathing and shortness of breath or even death. A human body is able to adapt only to a low concentration of CO_2 in the air. However, a long exposure to such air has subnarcotic effects. Human body is able to adapt to the concentration of CO_2 in the air equal to 2%. This concentration causes deeper breath and, as a result, other toxic substances produced by fire easily enter the human body and may cause death. A 5% concentration of CO_2 in the air provokes difficulty in breathing, vomiting, increased blood pressure, disorientation and, after prolonged exposure, loss of consciousness. A 7%–10% concentration of CO_2 in the air causes loss of consciousness and rapid death. Human beings have different levels of sensitivity to carbon dioxide.

Carbon monoxide CO is the product of an incomplete combustion of carbon. It is a colourless and odorless gas. It is highly toxic, combustible and is explosive in a mixture containing oxygen. Carbon monoxide is a part of many industrial gases (such as blast-furnace gas, coke oven gas, producer gas, exhaust gases etc.). The weight of 1 litre of CO is 1.25g (at 1 atm and 0 °C). Its density in relation to the density of the air is equal to 0.96, which means that carbon monoxide is slightly lighter in comparison with the atmospheric air. In the presence of oxygen, carbon monoxide burns at temperatures lower than 700 °C, producing carbon dioxide. Carbon monoxide is a highly toxic gas. Carbon monoxide has a high affinity to hemoglobin. It combines with hemoglobin to produce carboxyhemoglobin. As a result, the human body suffers from a lack of oxygen and dies of asphyxia. The lethal concentration of CO in the air is 4,000 ppm (0.4% of the air). The presence of any other toxicants increases its effects. Besides its principal effect, this gas also affects the nervous system, digestive system, endocrine glands, blood serum and the organs of hearing and vision. Due to the prevalence of CO in industrial gases, it causes approximately 50% of all industrial poisonings. As it also often occurs in enclosed places, it causes explosions.

Hydrocarbons are produced as intermediate products during a fire. They are combustible, often explosive and toxic. Hydrocarbons are a large group of compounds consisting of hydrogen and carbon. They are used in many industrial branches. Hydrocarbons may be formed naturally as well as industrially in all three common states of matter. At high temperatures and during a fire, they occur frequently in the gaseous state. Hydrocarbons serve as a raw mate-

An overview of toxicity rates of the chosen hydrocarbons. [2] Table 2.

Class	Danger level	Examples
0	Substance presenting no danger	Water, nitrogen, oxygen, helium, sodium chloride
A	Substance presenting a very low danger	Methane, carbon dioxide, ethanol
B	Slightly dangerous substance	Phosphoric acid, oxirane, ammonia
C	Moderately dangerous substance	Sulphur dioxide, nitrobenzene
D	Highly dangerous substance	Carbon monoxide, chlorine, potassium cyanide
E	Severely dangerous substance	Hydrogen sulphide, phosgene, hydrogen cyanide
F	Extremely dangerous substance	Tabun, nickel tetracarbonyl, tetraethyl phosphate

rial used in chemical industry. They are also used as fuels and solvents for pharmaceutical and cosmetic production, etc. The acute toxic effects of hydrocarbons affect the nervous system. Their effects are mostly narcotic and depressive. In a homologous series, the narcotic effect increases with the higher number of carbon atoms in a molecule. Alkanes and alkenes which have the same number of carbon atoms have the same narcotic effects. The effects of alkadienes, alkynes and cycloalkanes are stronger. The excitation effect of hydrocarbons is also very dangerous (especially for the firefighters) – it causes irritation or convulsions. Carcinogenic and mutagenic properties of aromatic and polyaromatic hydrocarbons do not occur during a fire. They strongly affect human health a few hours later. The immediate effects of hydrocarbons during a fire are irritation of the airways, eyes and skin. All types of hydrocarbons preferentially damage liver, kidneys, myocardium and blood vessels. The Toxicology and Chemical Substances code system (TCS) [2] classifies the particular substances according to their danger level in the following Table No. 2. The first capital letter in the table defines the rate of acute toxicity, the next letter in the table defines the rate of chronic toxicity. In case of a short exposure to fire (one work shift) the acute toxicity represents a bigger threat. In case of a prolonged exposure (several work shifts spent firefighting) chronic toxicity may appear. Some examples of toxicity rates of different substances can be seen in Table 2.

2.2 Toxic properties of chosen sulphurous compounds produced by a fire [2,5]

If a combustible matter contains sulphur in its molecule, carbon disulphide CS_2 may be an intermediate product of the combustion. This chemical compound is often used in chemical industry as a raw material or it is produced as an intermediate product and, in case of an emergency, it leaks into the air.

Carbon disuphide is a colourless, low-boiling liquid. Its vapours are highly flammable and it burns according to the following equation:

$$\mathbf{CS_2 + 3\ O_2 = CO_2 + 2\ SO_2}$$

In its pure form, carbon disulphide is aromatic; if produced industrially, it smells unpleasantly. It enters the human body through the airways or skin. The acute intoxication provokes incoordination, dizziness, delirium and hallucination. Later, it causes loss of consciousness or even death from respiratory paralysis. Chronic intoxication by carbon disulphide causes mental defects: excitement and depression. The intoxication also causes hypotension. The lethal dose of carbon disulphide is 5,000 ppm (0.5% of the volume of the air).

The end product of combustion of sulphur compounds is *sulphur dioxide* SO_2, a colourless gas with a pungent odor. It is heavier than the air (its density in relation to the density of the air is 2.2). It dissolves well in water and the resulting solution is called sulphurous acid. This solution has reduction properties and causes corrosion of metal structures or equipment. In the form of acid rains, it affects the pH of soils and vegetation. Sulphur dioxide is a toxic gas and has a negative influence on plants and animals. It causes the dying out of leaves of plants, their whitening and browning. The major influence of SO_2 on an adult is its irritating effect. It irritates moist mucous membranes (e.g. eyes, nose, mouth, but also skin), particularly the upper respiratory tract. A small acute toxication causes bronchitis and conjunctivitis. Longer exposure to sulphur dioxide (e.g. 500 ppm) causes apneusis, glottidospasm and, consequently, death.

Hydrogen sulphide H_2S is a gas with the characteristic odor of rotten eggs. It is slightly heavier than the air, it is soluble in water and forms an acidic solution. It is toxic and often causes serious intoxication. After it enters a human body, it reacts with many important enzymes and, therefore, it influences life functions. It has a negative influence on the central nervous system, which results in respiratory paralysis. It has irritating effects. The course of an acute intoxication may be very quick, especially during firefighting.

The symptoms of intoxication are:
- loss of consciousness,
- apneusis,
- cardiac arrest.

Even after the healing process visual, liver and kidney impairment persist. Besides the fact that hydrogen sulphide enters the body through respiratory organs, it is also absorbed through skin. It has good warning properties, because its smell can be detected

from a concentration of 0.3 ppm. Concentrations above 200 ppm cause impaired olfaction, a concentration of 600 ppm is lethal.

2.3. Toxic properties of chosen nitrogen compounds produced by a fire

Nitrogen compounds are often produced by a fire. They are products of combustion of natural flammable matters (such as wool, cotton, etc.) as well as of synthetic flammable matters (such as synthetic fibres, foamed or classic forms of plastic, etc.). The aforenamed matters are widely used in industry and engineering, in households as well as in social facilities. Other synthetic products of daily use which produce nitrogen compounds when burning are for example carpets, curtains, sofas and their covering and padding, etc. Combustive matters containing nitrogen atom in their molecules produce a wide range of inorganic and organic toxic products. Most frequently, these are: nitrogen oxides, ammonia, cyanide compounds and amines. At high temperatures nitrogen combines with oxygen to produce nitrogen monoxide NO.

Nitrogen monoxide NO is a colourless gas. It is volatile when exposed to the air. It quickly combines with oxygen to form nitrogen dioxide NO_2. In toxicology, the effects of nitrogen monoxide and nitrogen dioxide are summarized under a generic term "oxides of nitrogen" NO_x. Nitrogen monoxide has a negative influence on the central nervous system. It reacts with blood, specifically with hemoglobin, to form nitrosyl hemoglobin. In toxicology, nitrogen monoxide is considered to be a less toxic product of fire than nitrogen dioxide NO_2. NO_2 is a highly toxic oxide of nitrogen.

Nitrogen dioxide NO_2 is a reddish-brown liquid. At temperatures above 21 °C, it turns into a reddish-brown smoke. During a fire it occurs as a dimer N_2O_4 and its main toxic effect is irritation. Its harmful effects depend on its concentration and the length of exposure. At the concentration of only 35 ppm of NO_2 in the air the length of exposure should not exceed 5 minutes. Its immediate lethal concentration is 300 ppm. In case of intoxication by NO_2, there exists a so-called latent period (i.e. the time period between the inhalation of NO_2 and the appearance of the first symptoms of intoxication). After inhalation of NO_2 the intoxicated person may feel relatively well. However, the symptoms of intoxication appear 5 to 72 hours later.

The symptoms of intoxication are:
- decrease in blood pressure,
- inspissated blood,
- difficulty in breathing,
- pulmonary edema,
- apneusis,
- death.

The chronic effects of NO_2 include conjunctivitis, bronchitis and dental impairment. Longer exposure to NO_2 decreases immunity. Recently, a research has shown that NO_2 may even have carcinogenic effects. Another product of combustion and another cause of frequent industrial and transport accidents is ammonia NH_3.

Ammonia NH_3 is a colourless toxic gas with a choking odor. It is explosive and flammable when mixed with oxygen. Ammonia burns in oxygen with a yellow flame to produce nitrogen and water:

$$\mathbf{4\ NH_3 + 3\ O_2 = 2\ N_2 + 6\ H_2O}$$

Although ammonia is a toxic substance, it is easily recognizable – its pungent odor is recognizable at a concentration of 5 ppm. Due to its good solubility in water, it often irritates mucous membranes, eyes and the upper respiratory tract,
- it affects cornea and may cause corneal opacity,
- it irritates the central nervous system,
- it provokes convulsions,
- it causes hearing impairment and kidney impairment.

At a concentration of 5,000 ppm (0.5% of the air), it causes rapid death. At concentrations above 10,000 ppm, it damages skin and affects the airways even if they are well-protected. A conflagration of a natural as well as synthetic combustible matter containing nitrogen in its molecules produces a wide range of cyanide compounds and amines. Both of these groups are highly toxic.

Hydrogen cyanide HCN is a colourless liquid with a bitter almond-like odor. Hydrogen cyanide boils at 26.5 °C. During a fire it occurs in the gaseous state. It is highly toxic. It dissolves well in water and in the solution it dissociates according to the following equation:

$$\mathbf{HCN \rightleftharpoons H^+ + CN^-}$$

The cyanide anion halts cellular respiration. A lethal dose of hydrogen cyanide for an adult is 0.04–0.06g. This dose causes convulsions and rapid death. Some of the most common organic cyanide compounds are potassium cyanide KCN and sodium cyanide NaCN. They have typical cyanide effects, but their toxicity is slightly lower than that of HCN. Their lethal dose for an adult is 0.2–0.3g.

Plastic materials have become an integral part of our everyday life. The macromolecules which form these materials and, consequently, the products made of plastic are not toxic. When burning, the macromolecules dissolve to produce the original molecules. That way, amines are often produced by a fire. Amines are organic compounds which are highly toxic. Their acute toxicity is similar to that of cyanide compounds; their chronic toxicity is even higher and amines are usually assigned the highest toxicity rate in the toxicology code system. However, the cases of amine poisoning are not very common, as amines are easily distinguishable due to their pungent smell at low concentrations.

2.4. Toxic properties of phosphorus compounds produced by a fire

If contained in a combustible matter, phosphorus usually burns to produce its oxides (phosphorus trioxide P_2O_3 and phosphorus pentoxide P_2O_5). Both of these substances are solid (at 1 atm and

0 °C). When burning, they form dimers (phosphorus trioxide forms P_4O_6 and phosphorus pentoxide forms P_4O_{10}). Both of these oxides turn into the gaseous state during a fire.

Phosphorus trioxide P2O3 is obtained by the combustion of phosphorus in a limited supply of oxygen. Even at low temperatures, it combines with oxygen to form oxide of phosphorus. It is toxic and its acute effects are severely dangerous. It dissolves in cold water to form phosphorous acid H_3PO_3. The hot water dissolves both the oxide and the acid to form phosphane PH_3, which is, again, highly toxic. An intoxication by phosphorus compounds containing phosphorus with an oxidation number equal to 3 (PIII) affects the whole human body. The symptoms of intoxication are difficulty in breathing, stomach ache, decrease in blood pressure, nervous disorder and jaundice.

Phosphorus pentoxide P_2O_5 is obtained by a complete combustion of phosphorus. When exposed to the air, it gets wet and turns into a syrup. It is very hygroscopic and combines with water. This reaction is accompanied by a hissing sound. It is less toxic than P_2O_3 and its acute effects are only moderately dangerous (it provokes an irritating cough). Phosphorus pentoxide becomes dangerous when polluted by white phosphorus, which is classified as a severely dangerous substance.

3. Plastics in fire from a professional experience [7]

Fire in the Remiva plastic-recycling plant and storehouse in Chropyně, the Czech Republic, broke out at about 1 a.m. on Friday, 8th April 2011. At that time only a few night-shift workers were present in the factory. They all managed to escape from the site. The fire spread as far as 250 m from the focus during the night. The firefighting was inefficient as a strong wind was blowing and it was impossible to locate the fire. A helicopter was used to extinguish the fire from above. The fire produced a thick black smoke until Sunday evening. Even on Monday, when the firefighters extinguished all the centres of the fire, there was still smoke above the site. A powerful odor from the fire filled the air in the neighbouring area and due to intense firefighting, the local sewage treatment plant was unable to hold the excessive amounts of water. A change in winds made the firefighting even more complicated, as it carried the smoke to the town centre and to the nearby residential area. An irritating plume of smoke was rising from the burn-out area. The firefighters were measuring the concentration of toxicants in the air and forwarding the data to the headquarters and the officer in charge. The measurement of the concentration of toxicants showed that toxic substances were being emitted to the air. Due to their high concentration in the air, the officer in charge ordered an evacuation of the adjacent streets. Administrative authorities suggested an evacuation of approximately 300 people living in the area which was affected by the smoke. The firefighting was moreover complicated by a lack of water supply, because the fire also spread to a building containing water pumps. This made the use of hydrants impossible. The firefighters then had to organise shuttle traffic which carried water from a small lake. On Saturday morning, parts of the burn-out buildings collapsed, which caused an explosion of hot gases. On Saturday evening, the firefighters managed to extinguish the fire on two-thirds of the afflicted area. On Sunday, the experts of a fire rescue unit from Hlučín arrived to help with their heavy equipment. Without their participation it would have been impossible to access the largest focus which was hidden under the ruins. The firefighters managed to knock down one of the large walls and one of the factory buildings using heavy chains and the Tatra 815 vehicle. The experts from Hlučín finally accessed the last centre of the fire through the perforated ruins shortly before 5 p.m. The last centre of the fire, which resisted firefighting for three days, was consequently showered with water and low expansion foam. On the third day of the fire, the firefighters accessed the last large focus, which was the most dangerous of all. Water tanks, engines and aerial appliances dispersed large volumes of water and low expansion foam on the last few small hidden centres of the fire. After the fire had been located, the officer in charge cancelled the evacuation at 5 p.m. on Sunday afternoon and, after two days, the inhabitants returned to their homes. The site was fenced in order to prevent unauthorised persons from entering it and to preserve the evidence needed for further investigation of the causes of the fire. Firefighters from 67 professional, voluntary and corporate units from 4 regions of the Czech Republic rotated in the place trying to extinguish the fire. It was the most extensive fire in the history of the Moravian-Silesian Region. The owner of the company has not assessed the loss yet, but the first estimations state that the loss is tens of millions of Czech crowns. No lives were lost in the fire. Only two volunteer firefighters were injured. The company lost approximately 1500 tonnes of plastic materials because of the fire. According to the night-shift workers and the manager of the production, the first flames occurred on the roof of the factory building. However, it is difficult to establish where exactly the fire broke out. The investigation of the possible causes of the fire has only just begun.

4. Conclusion

Nowadays, plastic materials have become an indespensable part of our lives. Products made of plastic are used in building

Fig. 1 Fire in the manufacturing and logistics premises in Chropyne [7]

industry, transportation, mechanical engineering, in car, pharmaceutical and in many other industries; even our households are full of plastic products. The use of these materials has many advantages and disadvantages. The disadvantages are that the plastic materials are mostly flammable, they burn at high temperatures and they produce a wide range of dangerous and highly toxic substances. It is easier to extinguish a fire in a flat or in a house than in a factory building used for the production and storage of flammable materials (e.g. plastics). Therefore, it is utterly important to strictly maintain production process and workplace safety regulations. Fortunately, in the fire in the plastic-recycling plant in Chropyně no lives were lost. However, it is vital to remember that such fires have caused great property losses and killed many people worldwide. At present, the investigation of the Chropyně case has not been closed. Judging from the chemical composition of the burnt material, the fire produced many toxic substances in the form of intermediate and end products. Owing to favourable wind direction and dispersion, the toxicants from the smoke did not affect the health of the inhabitants.

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