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TABLE OF CONTENTS
(С О Д Р Ж И Н А)

461 – Igor Iliev, Zoran Markov
GRID DEPENDENCY AND RELAXATION OF AN ITERATION PROCEDURE FOR FLOW CALCULATIONS IN STATIONARY HYDRAULIC TURBINE PARTS
(Решавање на струењето во стационарните делови на хидрауличната турбина во зависност од густината на мрежата и релаксацијата на итеративната процедура) 121–127

462 – Darko Danev, Vase Jordanoska, Stevan Kjosevski
DETERMINATION OF LOAD LIMITS ON DRIVE SHAFTS IN HOT ROLLING MILL
(Определување на граничните оптоварувања на погонските вратила од валавничкиот стан во топла валавница) 129–138

463 – Dame Dimitrovski, Antonio Jovanovski
IMPACT OF ENERGY EFFICIENCY AND REPLACEMENT OF DIESEL FUEL WITH NATURAL GAS IN PUBLIC TRANSPORT ON REDUCING EMISSIONS OF NITROGEN OXIDES
(Влијанието на енергетската ефикасност и на замената на дизел-горивата со природен гас во јавниот транспорт врз намалувањето на емисиите на азотни оксиди) 139–142

464 – Igor Šešo, Slave Armenski, Done Taševski, Dame Dimitrovski
PERFORMANCE ASSESMENT OF SOLAR HEATING AND COOLING SYSTEMS
(Анализа и оцена на перформансите на системите за греење и ладење со сончева енергија) 143–156

465 – **Bojan R. Jovanovski, Dragan Šutevski, Radmil Polenakovik, Valentina Gečevska, Ivana Stankovska**
MODELLING THE SUCCESS OF SMALL AND MEDIUM ENTERPRISES
(Моделирање на успешноста на малите и средни претпријатија) 157–164

Instructions for authors 165–166

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GRID DEPENDENCY AND RELAXATION OF AN ITERATION PROCEDURE FOR FLOW CALCULATIONS IN STATIONARY HYDRAULIC TURBINE PARTS

Igor Iliev, Zoran Markov

"Ss. Cyril and Methodius" University in Skopje, Faculty of Mechanical Engineering,
Karpoš II bb, P.O. box 464, 1001 Skopje, Republic of Macedonia
igoriliev16@yahoo.com

A b s t r a c t: The numerical methods for iterative solving of discretized governing equations often require special treatment for the purpose of achieving not only sufficiently accurate and reliable results, but stable and gradual convergence of the solution too. The general remedy for such challenge, for a certain case, is to use a *fine mesh to a certain level* and/or to *slow down* the numerical procedure, a two useful strategies by which numerical instabilities will be avoided on the account of a greater CPU load. This paper presents the employment of these two strategies by conducting a grid dependency analysis for a 2D model of the stay and guide vanes of a hydraulic Francis turbine and furthering the solution to iteration procedure adjustment for a 3D representation of the same model. The ultimate accent is placed on how to deal with a particular numerical instability problem in a pure mathematical fashion without getting into the experimental validation of the results and calibration of the method.

Key words: grid dependency; relaxation; numerical instability; CFD; stay and guide vanes; tandem cascades; Francis turbine, fluid flow simulation

РЕШАВАЊЕ НА СТРУЕЊЕТО ВО СТАЦИОНАРНИТЕ ДЕЛОВИ НА ХИДРАУЛИЧНАТА ТУРБИНА ВО ЗАВИСНОСТ ОД ГУСТИНАТА НА МРЕЖАТА И РЕЛАКСАЦИЈАТА НА ИТЕРАТИВНАТА ПРОЦЕДУРА

А п с т р а к т: Нумеричките методи, кои се применуваат за итеративна пресметка на дискретизирани равенки кои опишуваат одредена појава, често бараат посебни третмани за да се постигнат не само реални и доволно точни решенија, но и стабилност и сигурна конвергенција на добиеното решение. Тоа најчесто се постигнува со примена на пресметковна мрежа со определена густина и/или со забрзување односно забавување на нумеричката процедура. На овој начин нумеричката дестабилизација ќе биде надмината на сметка на подолго време потребно за пресметка на проблемот. Според тоа, во овој труд е прикажана имплементацијата на двете споменати стратегии преку определување на потребната густина на дискретната мрежа за дводимензионално струење во статорските и спроводните лопатки на хидраулична Францисова турбина, а потоа е извршено управување со решавањето преку имплементација на метод на релаксација на постапката за пресметка на тридимензионален домен од истиот модел. Главниот акцент е даден на тоа како треба да се постапи со проблем од нумеричка стабилност од математичка гледна точка, без притоа да се навлегува во експериментална валидација на резултатите и калибрација на применетиот нумерички метод.

Клучни зборови: зависност на решението од густината на мрежата; релаксација на постапката; нумеричка нестабилност; CFD; статор и спроводен апарат; дворедни решетки; Францисова турбина; симулација на струење

INTRODUCTION

Turbomachinery research and development has encountered a massive usage of Computational Fluid Dynamics (CFD) technique in the recent years. This technique has the ability to lower the overall costs for development, speed-up the process and to bring the efficiency of turbines to a new upper level. This all is made possible by the latest advancements in computer technology and the development of efficient algorithms for iterative calculation and simulation of the behaviour of complex physical systems [1–4].

Any iterative method that is used for the prediction of the behaviour in a given physical situation or system is more or less based on a mathematical treatment. Starting from an initial guess and well defined boundary conditions, the solution advances through space and time in the discrete environment (the grid). However, the nature of discretization is such that some information is always being lost during the transfer of continuous equations into discrete counterparts. A certain error should always be expected and certain numerically instable results may occur from an overreaction of the iterative process.

Furthermore, the importance of grid quality is significant. It is often considered a bottleneck of the analysis process because of the lack of a fully automatic grid generation procedure which would result in grids of high quality in arbitrary cases. Several specialized computer programs have been developed in recent years which are adapted for high-quality turbomachinery grid generating. Even though the rate of convergence and the CPU time are mostly dependent on the grid resolution and quality, it turns out that the converged solution also converges in a way that for every finer grid it gradually approaches some certain value [5]. This type of convergence is also referred as *Grid Dependency* of the solution. The consequence of carefully designed discretization and solution technique is that the finer the grid is – the better the convergence and accuracy will be. However, there comes a critical turnover where an even finer grid will only bring insignificant convergence and accuracy improvements opposed by unjustifiably expensive associated computational costs. This is why grid dependency test is critical for an optimal simulation.

In its advanced stages, the iteration procedure also requires special treatment. In many cases, iteration methods are supplemented with relaxation techniques. Over-relaxation is often used to accelerate the convergence of iteration method and under-relaxation is sometimes used to achieve numerically stable results. The amount of over or under-relaxation used can be critical too. Too much leads to numerical instabilities, while too little slows down convergence. Selecting proper relaxation criteria can be a difficult and frustrating experience for users of computational fluid dynamics software since the criteria strongly depend on the specifics of the problem being solved [6].

THEORETHICAL BACKGROUND

The conservation equations governing fluid flow are given for a non-accelerating reference frame, but these equations are also applicable for *turbulent flow* by employing the *Reynolds decomposition* method [6, 7].

Continuity and momentum equations

The general form of the continuity equation can be derived from the law of conservation of mass and can be written in vector form as follows:

$$\frac{\partial \rho}{\partial t} + \nabla \cdot (\rho \bar{v}) = S_m, \quad (1)$$

where ρ is the density, t is the time, $\bar{v}$ is the velocity vector and S_m is a user defined mass source or sink which for our case is set to be zero. The continuity equation for incompressible steady flow is simplified to:

$$\nabla \cdot \bar{v} = 0. \quad (2)$$

The conservation of momentum in general vector form is described by:

$$\frac{\partial}{\partial t}(\rho \vec{v}) + \nabla \cdot (\rho \vec{v}\vec{v}) = S - \nabla p + \nabla \cdot (\bar{\bar{\tau}}) + \rho \vec{g} + \vec{F}, \quad (3)$$

where p is the static pressure, $\vec{F}$ is external body force and $\bar{\bar{\tau}}$ is the stress tensor given by:

$$\bar{\bar{\tau}} = \mu \left[(\nabla \vec{v}^T) - \frac{2}{3} \nabla \cdot \vec{v} I \right]. \quad (4)$$

Here μ is the molecular viscosity, I is the unit tensor and the second term on the right hand side is the effect of volume dilatation [6], which diminishes in the case of incompressible flow, by virtue of eq. (2).

Turbulence

For the purpose of resolving turbulence a two-equations, standard (k – ε) model is used, which is considered to be the workforce of practical engineering flow calculations [6]. The turbulent viscosity μ_t is computed by:

$$\nu_t = \rho C_\mu \frac{k^2}{\varepsilon}, \quad (5)$$

where $C\mu = 0.09$ is a constant, k is the kinetic energy of the turbulence and ε is its dissipation rate. These two turbulent properties are obtained from the transport equations proposed by Launder and Spalding [7].

Solver theory

The SIMPLE algorithm

The *S*emi-*I*mplicit *M*ethod for *P*ressure-*L*inked *E*quations (SIMPLE) is a procedure described and developed by Patankar and Spalding [8]. It is implemented in many CFD computer programs, among others in Fluent/ANSYS which is used for the calculations done in this paper. It is based on a special *pressure-correction equation*, derived from the continuity equation by integrating it over the control volume (the grid element). By this procedure, the momentum equations can be solved after the pressure field is estimated. The velocity components are calculated from their momentum equations using similar velocity-correction formulas.

Over the iteration procedure, the guessed pressure field is being corrected by the pressure and velocity correction equations until the resulting velocity filed will satisfy the continuity equation.

The order of execution of the operations are shown in the following block diagram (Fig. 1).

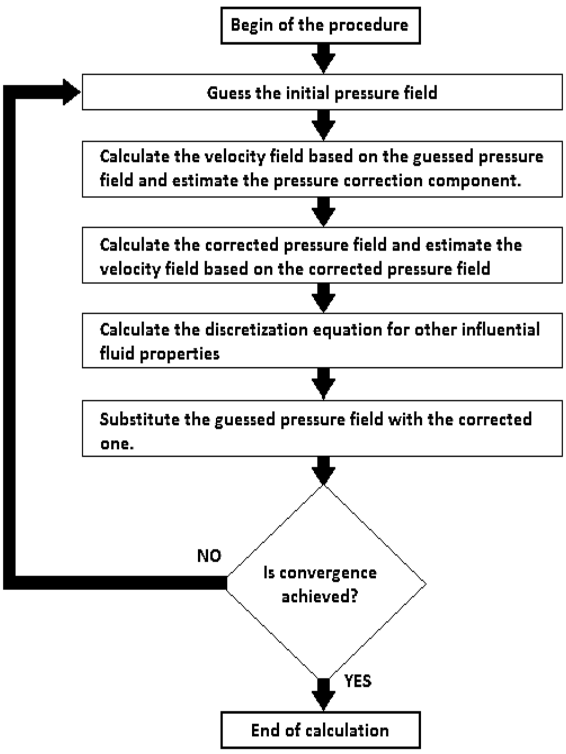

Fig. 1. The sequence of operations in SIMPLE

Explicit relaxation of variables

In *pressure-based* coupled algorithm, the relaxation technique is used for momentum, pressure, kinetic energy of turbulence and kinetic energy dissipation rate. The basic concept is to use the following equation for the change of ϕ, representing the value of the general variable within a cell, during each iteration:

$$\phi = \phi_{old} + \alpha \Delta \phi , \tag{6}$$

where the new value ϕ depends upon the old value ϕ_{old} and the computed change $\Delta\phi$ multiplied by the relaxation factor α.

When the value of α is between 0 and 1, its effect is under-relaxation, which means that for every iteration the values of ϕ stay closer to ϕ_{old}. When α is greater than 1, over-relaxation is produced and the iteration procedure is accelerated [9].

GRID DEPENDENCY TEST AND NUMERICAL STABILIZATION IN FLUENT/ANSYS

Grid dependency test

The grid dependency test is done for the stationary inlet part of a hydraulic Francis turbine consisting of: spiral case, stay blades and guide vanes, as shown in Fig. 2. The computational domain is simplified to a two-dimensional blade-to-blade plane cut of the geometry.

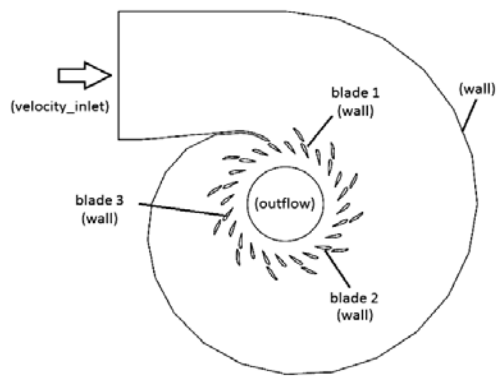

Fig. 2. The two-dimensional computational domain used for grid dependency test

The grid for the model is created from unstructured quadrilateral elements with end-wall boundary layer treatment. The same meshing procedure is used to generate five different grids with elements density varying from 20.000 to 700.000, as shown in Fig. 3 below. The number of needed iterations for complete convergence and computing times for a single CPU calculation (with nonparallel usage of Intel Quad Core i7 2630 QM) are also shown under every image.

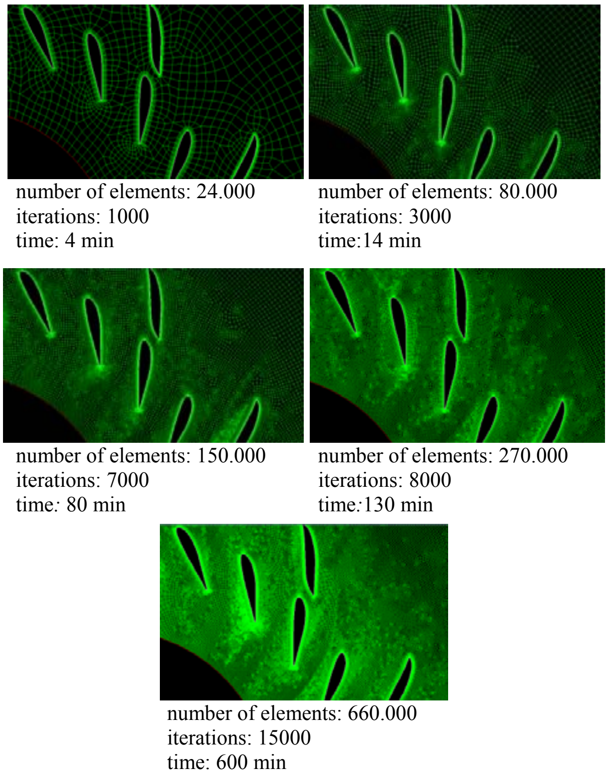

Fig. 3. View of the 2D grids with different elements densities for grid dependency test

The model is generated using specialized CAD software and is exported in Gambit/ANSYS where the grid is generated and boundary conditions are being defined. The calculation process begins from the inlet zone and the solution initialization is done with the following parameters in Fluent/ANSYS:

Table 1

Solution initialization parameters

Parameter	Value
Inlet velocity	$v = 5$ m/s
Operating pressure	$p = 300.000$ Pa
Turbulence	$k - \varepsilon$ standard model
Fluid	Water: $\rho = 998.2$ kg/m^3 $m = 0{,}001003$ kg/ms
Inlet boundary	Velocity inlet method
Outlet boundary	Outflow method
Walls	Standard no-slip function

Typically, stationary calculations for 2D require not more than 3000 iterations to generate practical and reliable results, where the calculations are stopped after the scaled residuals fall below the level of 1e–4. For the grid dependency test done in this paper, the calculations are stopped after the scaled residuals became clearly saturated and turned into straight horizontal lines (not much below the level of 1e–7). It is apparent that this "additional accuracy", or the level of saturated residuals, needs increasing number of iterations as the grid gets finer.

A calculation of the resulting forces in guide vanes 1 to 3 (Fig. 2) is done for every grid and their normalized values, with respect to the values obtained from the first grid (the grid with 24.000 elements), are shown in Fig. 4.

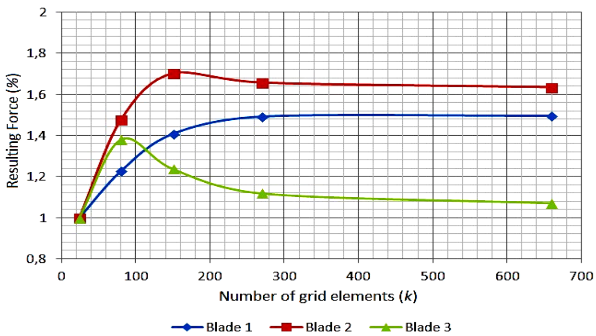

Fig. 4. The change of the resulting forces for different grid densities

The trend lines (Fig. 3) show that considerable differences in values occur under the number of 300.000 elements of the grid, where the typical element/cell size Δs, in the region between the guide blades, normalized with the length of the blade l, has the value of 1.5 $e - 2$. It is evident that for finer grids (above 300k of elements) the trend line asymptotically approaches certain values with only 2–4% change in value but big differences in CPU time (see Fig. 3). From this test it can be concluded that for 2D calculation of the flow in stationary inlet parts of hydraulic Francis turbine, the grid should have at least 300.000 elements or more.

Numerical stability control

After adoption of the recommended grid density (section above) the discussion is furthered to a three-dimensional calculation. This time the problem boils down to the calculation of the stationary, turbulent flow field for the tandem cascade (stay and guide vanes, Fig. 5). A periodic section of the cascade is being selected for the purpose to lower down the calculation time.

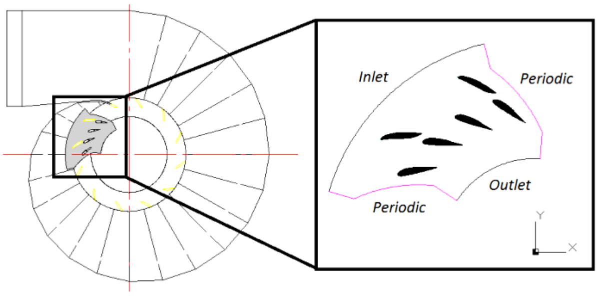

Fig. 5. Simplification of the three-dimensional computational domain for the tandem cascade flow calculation

The influence of the spiral case is replaced with a uniform flow field consisting of radial and angular components of the inlet velocity. The interdependence between these components for the inlet of the domain is being calculated using the following equation, derived specifically for this case in [10]:

$$v_{ang.} = 11775 \cdot v_{rad.} \quad (7)$$

The same solution initialization parameters (Table 1) are applied and the calculation is started with laminar flow model first. Then, after 300 iterations, turbulence model is being employed for the next 1000 iterations. It is recommended that turbulent flow calculations should sometimes begin with laminar flow model first, as this can be beneficial for the computational time, stability and the convergence of the solution. But, for the model solved in this paper, it is evident (Fig. 6) that a laminar flow model doesn't provides the desired effects and it should simply be omitted in any further calculations. The normalized residuals history for the continuity, velocity components, and turbulence parameters are shown in Fig. 6.

The residual history diagram shows excessive pulsations of the flow properties both for laminar and turbulent calculation. It is reasonable to conclude that this numerical instability might greatly result from the periodic boundary conditions used in the model. This evident overreaction of the iterative procedure can be effectively defused by applying under-relaxation criteria and choosing different spatial discretization schemes for momentum and turbulence.

In that direction, the default parameters were overridden with new ones, obtained by conducting a trial-and-error adjustments in order to get good results. The new values are shown in the table 2 that follows:

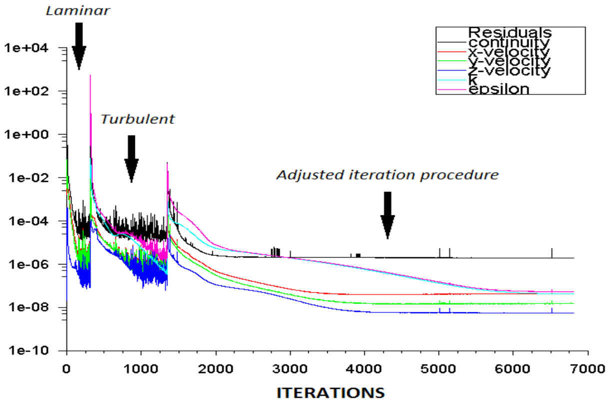

Fig. 6. Residuals history diagram

Table 2

Adjusted parameters of the iteration procedure

Parameter	Scheme	α-factor
Momentum	Second Order Upwind	0.7
k	Second Order Upwind	0.6
ε	Second Order Upwind	0.6

From Figure 6 can be seen that after the adjustments of the iteration procedure the instability is exceeded and reasonable convergence and computational time are achieved. As illustration, the following Figure 7 shows the resulting three dimensional velocity-coloured streamlines for the calculated flow field.

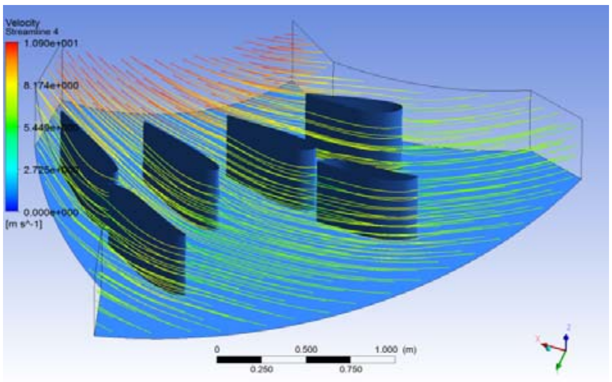

Fig. 7. Calculated streamlines for the 3D tandem cascade

The velocity vectors and the contours of the pressure distributions are shown for the top side of the model in Fig. 8.

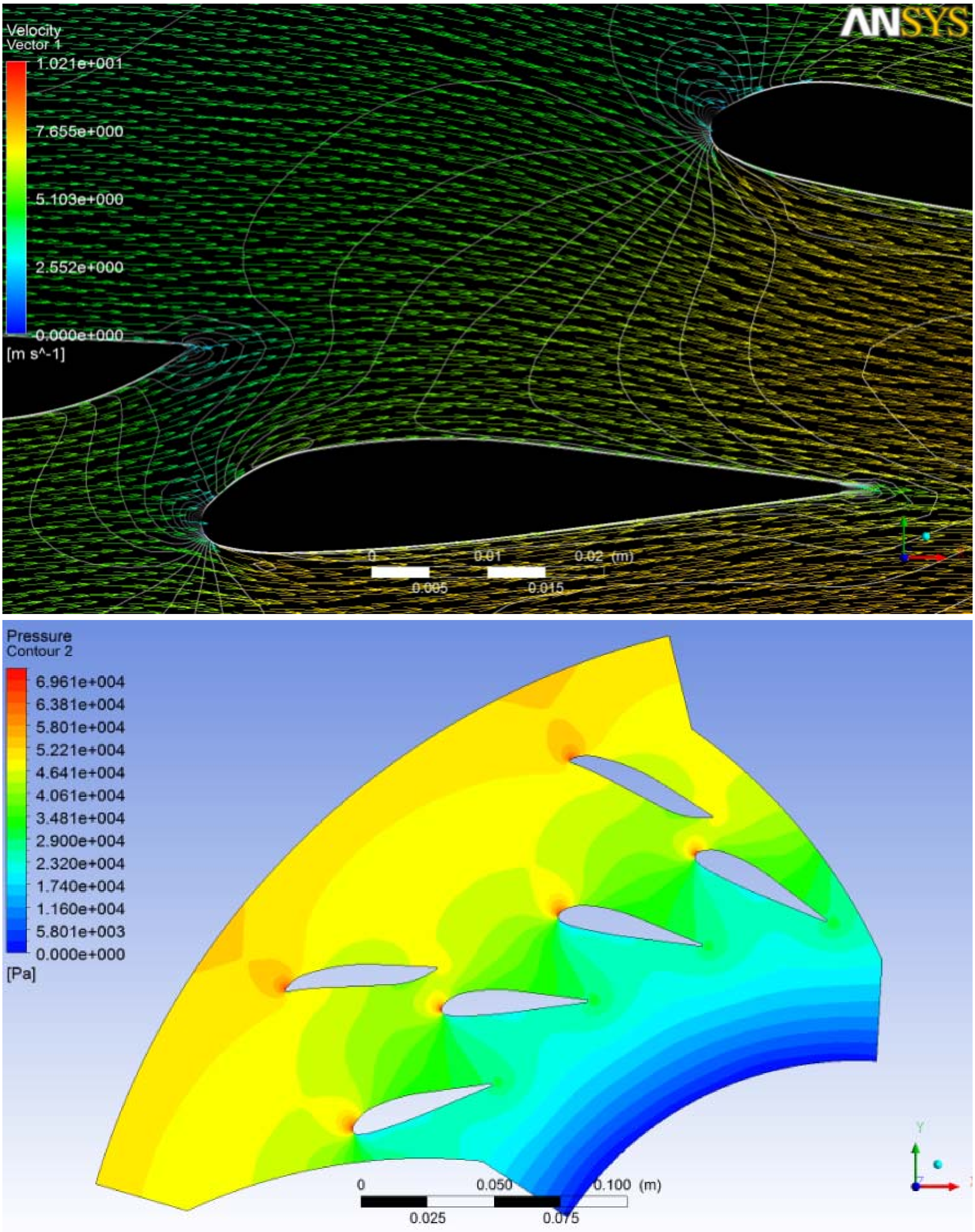

Fig. 8. Velocity vectors and static pressure distribution contours shown in the top side of the model

CONCLUSIONS

From the performed tests and calculations it can be seen that solution accuracy is strongly dependent on the elements density and the type of the grid. As shown in this paper, the minimum amount of grid elements should be selected by conducting a grid dependency test. It is determined that, for a two-dimensional calculation of the flow field in stationary inlet parts of hydraulic Francis turbine, the unstructured quadrilateral computational grid should not have less than 300k elements, where the normalized element/cell size in the region between the guide blades has the value of approximately 1,5e-2.

Furthermore, due to the specifications of the model being solved, a certain numerical instability of the solution may occur. This should be expected especially when using periodic boundary conditions for simplification of the model. As shown in Fig. 6, this instability may occur for both laminar and turbulent calculation and therefore laminar flow model should be omitted. By the aid of relaxation of the numerical procedure, it is estimated, by trial-and-error adjustments, that reasonable numerical stability for such flow simulations can be achieved when employing under-relaxation procedure and Second Order Upwind spatial discretization scheme. From Fig. 6 is also evident that few iterations could be saved as from 4000 to 7000 steps no substantial differences in the results are achieved. Consequently, 3000 iteration steps are sufficiently enough with proper adjustment of the iteration procedure from the very beginning of the calculation.

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Original scientific paper

DETERMINATION OF LOAD LIMITS ON DRIVE SHAFTS IN HOT ROLLING MILL

Darko Danev, Vase Jordanoska, Stevan Kjosevski

"Ss. Cyril and Methodius" University in Skopje, Faculty of Mechanical Engineering,
Institute of Nechanical Construction, Mechanization and Motor Vehicles,
Karpoš II bb, P.O. box 464, 1001 Skopje, Republic of Macedonia
darko.danev@mf.edu.mk

A b s t r a c t: Drive shaft breakages in rolling mills generate great material losses. Improving the strength characteristics of drive shafts should provide shafts to withstand the maximum loading during the rolling process. Breaking in the shaft critical section may occur when the value of the torque is greater than the value of the torsion moment which can cause plastic flow in the whole cross section. Theoretical calculations and experimental tests were done. The experiment showed that the maximum rolling torque of the upper shaft has a higher value than the torque limit at permanent torsion dynamic strength. The available safety reserves in the critical section were small, only 27%. To increase the strength characteristics, changing in the cross-section design and in material quality for shafts should be done.

Key words: strength characteristics; drive shafts; torque

ОПРЕДЕЛУВАЊЕ НА ГРАНИЧНИТЕ ОПТОВАРУВАЊА НА ПОГОНСКИТЕ ВРАТИЛА ОД ВАЛАВНИЧКИОТ СТАН ВО ТОПЛА ВАЛАВНИЦА

А п с т р а к т: Ломовите на погонските вратила во топлите валавници генерираат големи материјални загуби. Подобрувањето на јакосните карактеристики на погонските вратила треба да обезбеди вратилата да го издржат максималното оптоварување кое се јавува во процесот на валање. Нагло кршење на вратилото може да настане во критичниот пресек во моментот на појава на вртежен момент кој ќе биде поголем од вредноста на моментот кој ќе предизвика напон на течење во целиот напречен пресек. Спроведени се теоретски пресметки и направено е експериментално испитување. Експериментот покажа дека максималните моменти од валање на горното вратило имаат значително повисока вредност од оптоварувањата на долното вратило при трајна динамичка јакост на торзија. Расположливата резерва на сигурност во критичниот пресек е мала, само 27%. За зголемување на јакосните карактеристики треба да се направи промена во димензиите во критичниот пресек на вратилото и да се изврши промена на материјалот за вратилата.

Клучни зборови: јакосни карактеристики; погонски вратила; вртежен момент

INTRODUCTION

Occurrence of breakages on drive shafts of rolling mill has led to perform increasing of load limit on shafts through strengthening of their structural characteristics in critical sections.

Strengthening should provide shaft to withstand higher loadings than the loadings that can be borne by the working roller sleeve.

In order to achieve this aim, the following methodology is applied:

– Theoretical considerations of factors that can affect the initial appearance of fatigue or breakage on the shaft.

– Theoretical analysis of the structural characteristics of the drive shafts in terms of evaluating the possibility of increasing their strength characteristics.

– Designing a system for direct testing and for determination of actual torque loading on the drive shafts and of the force from the pressure cell with acquisition of the measurement results.

– Performing tests in real working conditions and getting a test results.

– Analysis of test results and carrying out conclusions regarding the relevant magnitudes of loadings, which will serve as a basis for evaluation of strength characteristics in shaft's critical section.

– In order to increase the level of the strength characteristics, i.e. to increase the level of loadings limit above the sleeve critical loadings, proposing measures regarding the change of framework in the critical section and of the material quality for the shafts.

THEORETICAL CALCULATIONS

Factors which could influnce on initial appearance of fatigue or breaking of the shaft

Factors that could affect the occurrence of fatigue or quick breaking in the critical section of the shaft [10] can be because of:

– Occurrence of torque that will cause greater value of the tangent stress in outer fibers of the shaft then the tangent stress of the material permanent dynamic load allowance at variable alternate loading.

– Occurrence of a torque greater than the value of a moment that will cause tangent stress of plastic flow in the critical cross-section. That torque could basically be equated with a value of fictional static moment which might cause tangent stress of plastic flow τ_T because of torsion.

Reasons that can additionaly initate increasing of torque while hot rolling are: cooling of the ends and insufficient heating of the piece that is rolled, inadequate reduction of the piece and jam in the process of rolling, etc. In such cases because of the increased rolling resistance it comes to "small brakings", i.e. a sharp decrease in the angular velocity of rotational masses from the power assembly (rottors, clutches, drive shafts) leads to appearance of first moment of inertia.

In real exploitation conditions often of the first moment of inertia significantly exceeds the reserves arising from structural specified degree of reliability in the critical section. This situation is demonstrated many times in the analysis of the reasons for breaking the drive shafts and working rollers sleeves.

Drive shaft characteristics

Shaft dimensions

Drive shaft according to the present construction shown in Figure 1 is characterized by a critical section shown in Figure 2. Marking index "$_s$" (e.g. d_s, r_s, etc.) refers to the present (old) solution, and marking index "$_n$" (e.g. d_n, r_n, etc.) refers to the proposal of a new shaft solution.

Stress concentration coefficient in the critical section of the shaft [8]

Critical section characteristics of the existing shaft:

– diameter of the shaft bearing $D = 660.4$ mm,

– diameter of the shaft in the critical section $d_s = 512$ mm,

– radius of transition in the critical section $r_s = 25$ mm,

– first moment of inertia of the shaft in the critical section $W_{os} = 26843545$ mm^3.

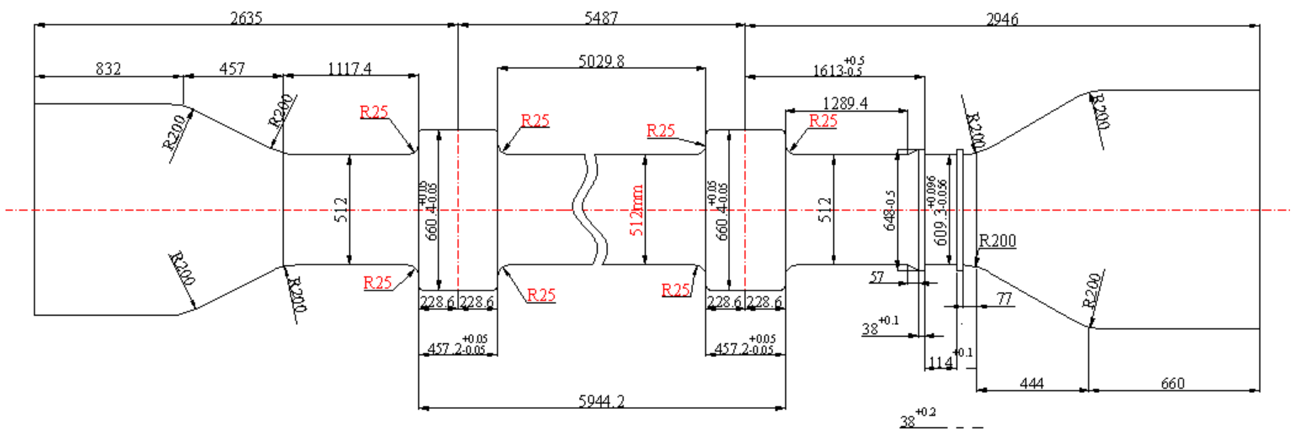

Fig. 1. Drive shaft dimensions

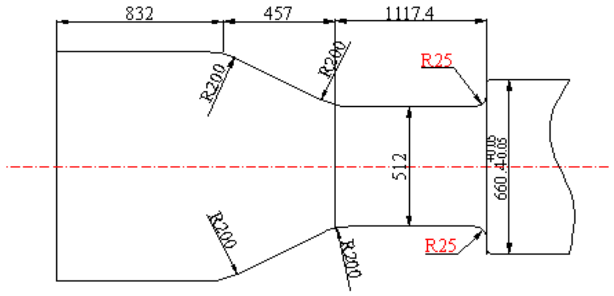

Fig. 2. Dimension of the critical section

Stress concentration factor in critical section is calculated according to the expression:

$$K_{cs} = 1 + \eta \cdot (k_r - 1)\,, \qquad (1)$$

where:

a) η is stress concentration factor due to change in the critical section diameter. For D/d_s = 1.2898 η is determined to be 0.84;

b) k_r is stress concentration correctional coefficient which depends on the ratio r_s/d_s and on the sensitivity of the material of which the shaft is made. For r_s/d_s = 0.05 and for the anticipated quality of the material according to technical documentation, k_r = 1.5.

Based on the expression (1) stress concentration factor in the critical section is K_{cs} = 1.42.

Characteristics of material of which drive shafts are made

The chemical composition of the material according to technical documentation is: C = 0.41 ÷ 0.47%; Mn = 0.80 ÷ 0.90%; Si = 0.05 ÷ 0.35%; S = 0.5% max; P = 0.5% max.

The material with specified chemical composition after tempering and improvement has the following mechanical properties:

– breaking strength σ_m = 620 MPa – minimum;

– yield strength σ_T = 310 MPa – minimum.

The permanent dynamic strength of this material is determined by comparing the literature data for known material chemical composition and its mechanical properties and approximately best fits C45 (EN 10083/2) or respectively C35 (EN 10083/2) [11]. About specified materials the permanent tensile dynamic strength and permanent torsion dynamic strength at variable alternate loading are:

σ_D = 200 ÷ 240 MPa
τ_D = 160 ÷ 200 MPa
HB = 172 – 206

Calculation of moment limits

The static moment limit of torsion which causes plastic flow of the material through whole cross-section of the shaft with diameter d_s and the first moment of inertia in critical section $W_o = W_{os}$, taking into account the influence of the stress concentration factor K_{cs} due to the changes in cross-section diameter [5, 6, 10], is:

$$T_{gr} = W_0 \cdot \tau_{gr} / K_{cs} = 4500 \text{ kNm..}$$

Torsion moment limit which can cause load to the rank of permanent torsion dynamic strenght in the critical section of minimum value of 160 MPa, equals:

$$T_{gr,D} = W_0 \cdot \tau_{gr,D} / K_{cs} = 3042 \text{ kNm.}$$

Calculation of shaft safety degree from the perspective of the power engine loading

Based on the declared data about the torque of power electric motor which equals T_n = 890 kNm derives:

a) Safety degree against breaking S_a is ratio between the static moment limit of torsion causing a plastic flow through the whole cross-section (T_{gr}) and the nominal torque of the electric motor, i.e.:

$$S_0 - \frac{T_{gr}}{T_n} = 5.05. \qquad (2)$$

b) Safety degree against breaking S_b is ratio between the static moment limit of plastic flow (breaking) and the maximum torque that can be realized by the electric motor with $T_{e\,\max}$ = 2.25T_n, i.e.:

$$S_b - \frac{T_{gr}}{T_{e\max}} = 2.24. \qquad (3)$$

c) Maximum safety degree S_c is ratio between the moment at permanent torsion dynamic strenght and the nominal torque of the electric motor, i.e.:

$$S_c - \frac{T_{gr,Dr}}{T_n} = 3.39. \qquad (4)$$

d) Safety degree S_d is ratio between the moment at permanent torsion dynamic strenght and the maximum torque that can be realized by the electric motor, i.e.:

$$S_d - \frac{T_{gr,D}}{T_{e\max}} = 1.519. \qquad (5)$$

Analyzing the values of the safety degrees on the stated grounds it is concluded that the critical section according to the current strength characteristics is not affected by electromotors torque. This leads to the conclusion that the shaft started crashing due to further increase of the torque value generated by the inertia of the other rotational masses.

EXPERIMENTAL RESULTS

In order to determine the real level of loading in the shafts critical sections during hot rolling, according to previously developed methodology, actual testing was conducted.

Test measures

a) Measure for determining of shaft loading is torque transferred by the drive shafts during the process of hot rolling.

b) Comparisons with the calculated torque generated by the electromotors were done in order to compare the measured torque values.

Testing equipment

The defined methodology includes use of tensiometric method to perform a direct measurement of work shaft torque. Strain gauges tied in Wheatstone bridge were applied on the both shafts (upper and lower). They were connected with miniature wireless acquisition connectivity modules which were transmitting the signal to wireless analogue output modules, connected to HBM universal amplifier. Amplifier was connected to PC, which with the software Catman Easy was allowing to see the data acquisition in real time and record it [2].

To measure the force of pressure in the pressure cell, pressure transducer was used [7, 9].

In Figure 3, mark 1 indicates the torque measuring points on the shaft, and mark 2 shows the pressure measuring point in pressure cell.

Figure 4 shows the positioning of the measuring point on the surface of the lower power shaft.

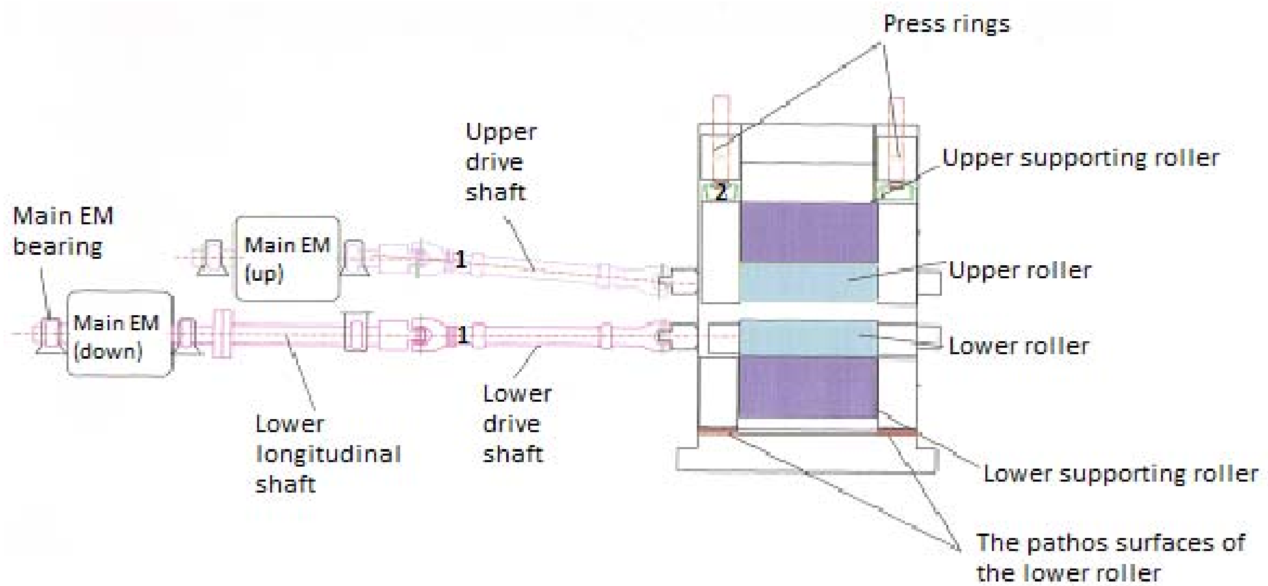

Fig. 3. Schematic view of the system and of the measuring points

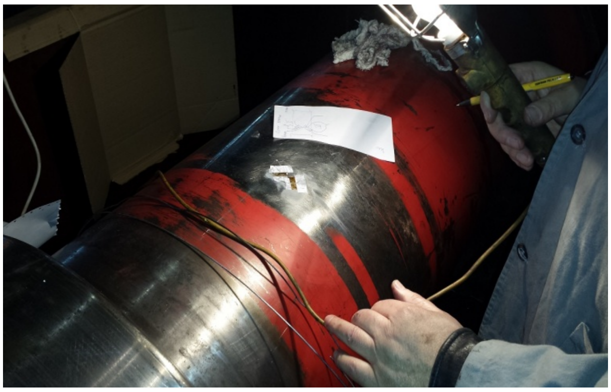

Fig. 4. Positioning of strain gauges on the lower shaft

Hot rolling program while testing

Although the intention to conduct exploitation tests was to determine the nominal and critical modes of loading at rolling, however due to the power characteristics, the experiment is conducted in real exploitation conditions according to the regular program.

Test results

Extensive information is gathered based on the conducted tests. Test results are displayed graphically and in tables because of the need of the experiment. Only individual maximum values of the torque while rolling are given in the tables [3]. For such time sequences, data about the calculated values of rolling torque obtained from the current magnitudes are included in the tables [T_p].

In tables also are given the values of the absolute difference between the torque obtained by measurements and by calculations.

According to the program available in real exploitation conditions, the obtained test results are generated in the output values of voltage change in volts, V.

Samples that came into being at higher loads on the power shafts are extracted, separately for the upper and the lower shaft and force results from the pressure cell are also shown.

Figure 5 shows diagrammatic record of hot rolling process of six sheets.

In the example on Figure 5 changes are displayed color-coded as follows:

– blue: shows the changes in the torsion moment on the upper shaft;

– green: shows the changes in the torsion moment on the lower shaft;

– red: shows the changes of the force in the pressure cell.

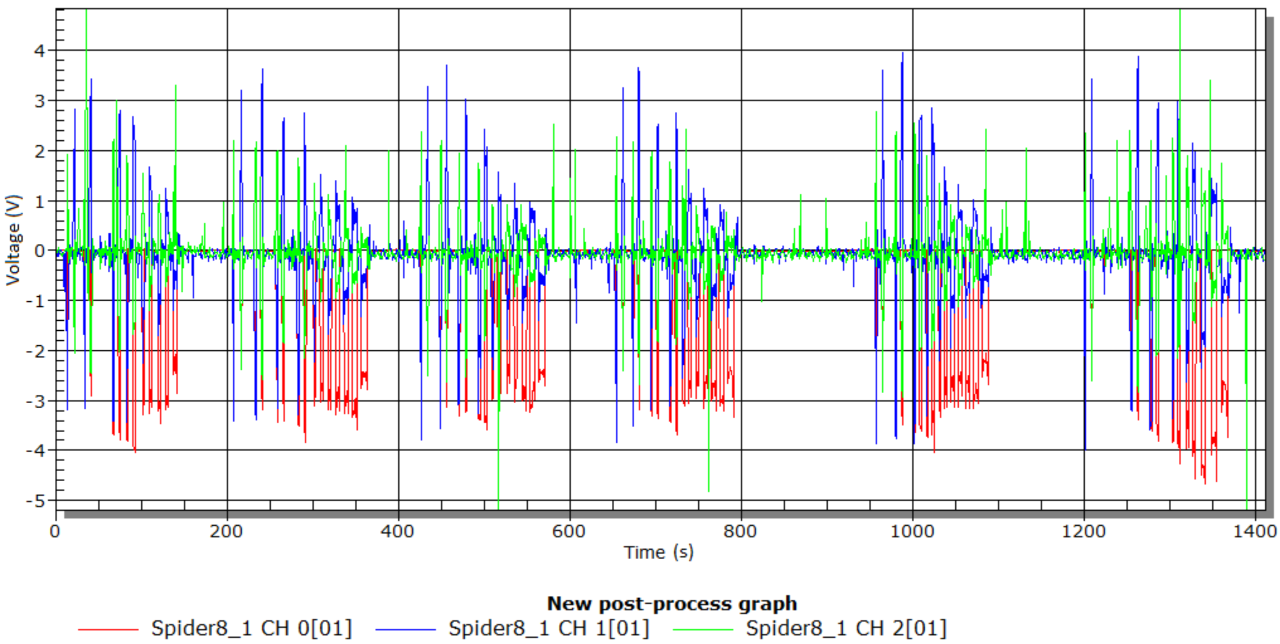

Fig. 5. Results from hot rolling process of six sheets

Calculation of the torque measured on the shafts by tensiometric method, during the processing of the measurement magnitudes is determined by the expression:

$$T = \frac{1}{2} \cdot \varepsilon_i \cdot G \cdot W_0 . \tag{6}$$

With the replacement $G = \frac{E}{2 \cdot (1+\mu)}$ the expression (6) takes the form:

$$T = \frac{1}{4} \cdot \varepsilon_i \cdot \frac{E}{1+\mu} \cdot W_0 , \tag{7}$$

where:

ε_i – value of dilation measured during the test, μm/m;

G – shaft material shear module, daN/cm^2;

E – shaft material elastic module, daN/cm^2;

μ – material Poisson's ratio;

W_0 – first moment of inertia in the measured cross-section.

The dimension of the ordinate about dilation which in the diagrams was obtained in volts, V is transformed into μm/m, i.e. about the pressure from volts, V is transformed into bar. The transformation is done with calibration coefficients as follows [1]:

– ε_i calibration: 1 V = 400 μm/m (8)

– torsion moment: $T = 1.0840 \cdot \varepsilon_I$ kNm (9)

– p pressure calibration: 1 V = 50 bar (10)

– force in pressure cells: $F = 8.820 \cdot$ p t (11)

Test result presentation

Figure 6 shows the changes in torque on the upper and the lower shaft in volts, V, and also the change of the press force from one cell in volts, V, during the whole process of hot rolling of 13 isthmuses. Figure 7 shows the changes just for the first isthmus.

Using the relations defined by expressions 8, 9, 10 and 11, Table 1 presents the values of shaft measured torque about all thirteen isthmuses while rolling one sheet.

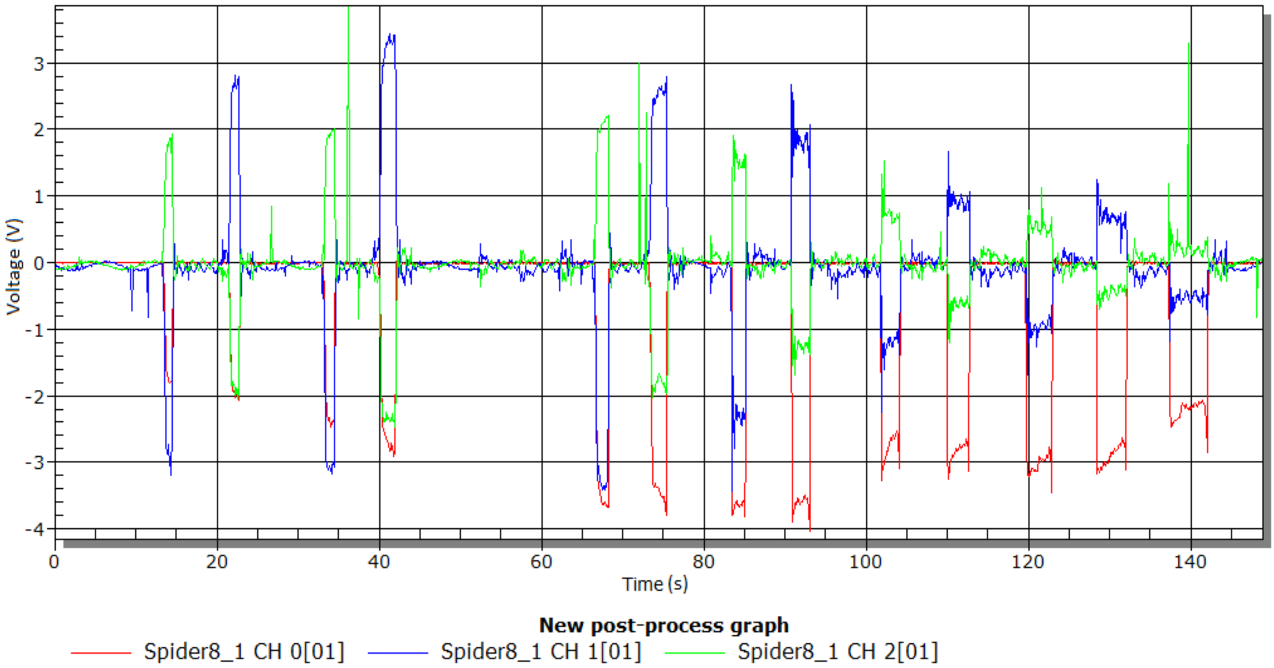

Fig. 6. Changes in torque and in press force (red) during the hot rolling of 13 isthmuses

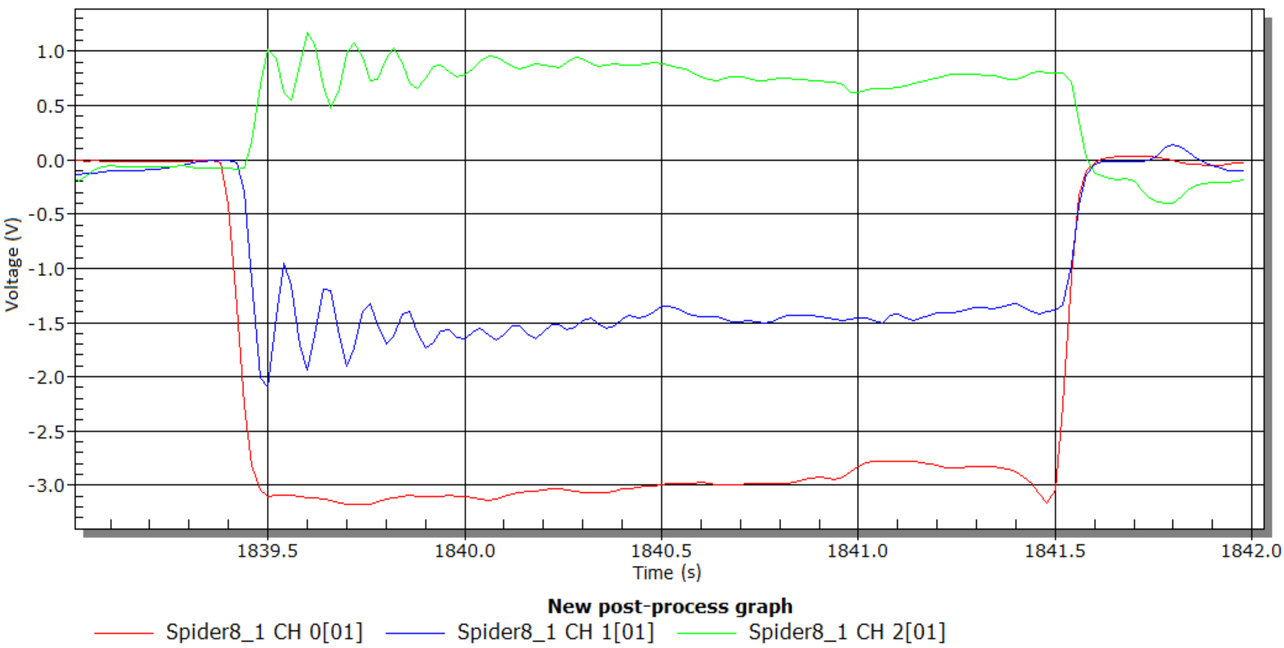

Fig. 7. Changes in torque and in press force (red) for one isthmus

Table 1

Nr. of isthmuses	Dilatation, V		Dilatation, μm/m		Torque, kNm		
	ε_g	ε_d	ε_g	ε_d	T_g	T_d	$T = T_g + T_d$
1	3.2	1.9	1280	760	1290	823	2113
2	2.8	2.1	1120	840	1214	910	2124
3	3.3	2.0	1320	800	1430	867	2297
4	3.6	2.5	1400	1000	1517	1084	2601
5	3.5	2.2	1400	880	1517	954	2471
6	2.9	2.0	1160	800	1257	867	2124
7	3.6	1.9	1280	760	1290	823	2113
8	2.8	1.5	1120	600	1290	650	1940
9	2.25	1.5	900	600	975	650	1625
10	1.7	1.3	680	520	737	563	1300
11	1.7	1.1	680	440	737	475	1212
12	1.3	0.7	520	280	563	303	866
13	1.3	0.6	520	240	563	260	823

T_g – torque measured on upper shaft
T_d – torque measured on lower shaft

The differences between the values of the torque which are obtained by measurements and the calculated values through current magnitudes per isthmus about the sheet are given in Table 2.

Table 2

Nr. of isthimuses	Torque, kNm		
	Calculated T_p	Measured T_i	Ratio % $(T_p–T_i)/T_p$*100
1	2656	2113	20.4
2	2492	2124	14.8
3	2850	2297	19.4
4	3134	2601	17.0
5	3030	2471	18.4
6	2622	2124	19.0
7	2408	2113	12.3
8	1870	1940	–3.7
9	1110	1625	–46.4
10	904	1300	–43.8
11	824	1214	–47.3
12	672	866	–28.9
13	370	823	–122.4

Based on test records of total 17 selected specimens, Table 3 presents the processed results for the maximum values of torque and Table 4 presents the values at maximum press force that came into particular isthmuses for each sheet separately.

Table 3

Nr. of sheet	Dimensions, mm			Max. torque	
	δ	b	l	T_{gi}	T_i
1	7	3050	6330	1517	2601
2	7	3050	6330	1724	2861
3	7	3050	6330	1724	2755
4	7	3050	6330	1834	2861
5	7	3050	6330	1834	2991
6	7	3050	6330	1834	2818
7	38	2300	12000	1951	3338
8	30	2000	12000	2081	3468
9	30	2000	12000	2293	4249
10	52	1900	8800	2293	3902
11	18	2480	13750	1834	2948
12	6	2500	8000	2201	3338
13	6	2500	10000	2017	3208
14	6	2500	10000	2400	3902
15	5	2500	10000	2293	3642
16	5	2500	10000	2025	3338
17	5.5	3000	12500	1605	2529

T_{gi}, kNm – maximum torque measured at upper shaft while rolling
T_i, kNm – total maximum torque measured while rolling

Table 4

Nr. of sheet	Dimensions, mm			Max. torque		
	δ	b	l	T_p	T_i	T%
1	7	3050	6330	1870	1907	–2.0
2	7	3050	6330	2166	2341	–8.1
3	7	3050	6330	1990	1734	12.9
4	7	3050	6330	2296	2037	11.3
5	7	3050	6330	1884	2037	–8.1
6	7	3050	6330	1228	1517	–23.5
7	38	2300	12000	2632	2601	0.1
8	30	2000	12000	3062	3035	0.9
9	30	2000	12000	3656	4249	–16.2
10	52	1900	8800	3380	3902	–15.4
11	18	2480	13750	3186	3035	4.7
12	6	2500	8000	3146	3121	0.8
13	6	2500	10000	3294	3208	2.6
14	6	2500	10000	3058	3902	–27.6
15	5	2500	10000	2440	3468	–42.1
16	5	2500	10000	2634	2775	–5.4
17	5,5	3000	12500	2804	2529	9.8

T_p, kNm – total torque obtained from the rolling program for both shafts
T_i, kNm – total maximum torque measured while rolling for both shafts
T (%) – $(T_p – T_i) \cdot 100/T_p$ – torque percentage proportion

Test results analysis

The results presented in Table 3 about T_{gi} are showing that maximum rolling torque of the upper shaft has a higher value therefore for further analysis only those loadings were taken into account.

Diagrams and tables can lead to the conclusions, as follows:

The maximum rolling torque of the upper shaft occurred during the test process reaches value: $T_{\max}$ = 2300 to 2400 daNm (Table 3, sheet number 14).

Starting from the statement that $T_{\max}$ had value of 2400 daNm, it will be used for further calculations and analyses.

The maximum total press force throughout the test process [4], reaches the value: $F_{p\max}$ = 3500 to 4250 t.

Determination of safety degree regarding the maximum rolling torque specified by the tests

1) Safety degree of the shaft critical section from a sudden breaking is a ratio between the static moment limit of torsion which causes plastic flow through the whole cross-section (breaking in the critical section, T_{gr}) and the maximum moment measured during the tests on the upper shaft and equals:

$$S = \frac{T_{gr}}{T_{\max}} = 1.87 .$$

2) Minimum safety degree which is a proportion of the value exceeding the minimum limit value of the torsion moment at permanent dynamic strength related to the initial cracking of the outer fibers in the critical section and the maximum moment measured during the tests on the upper shaft, equals:

$$S_{\min} = \frac{T_{gr,D}}{T_{\max}} = 1.27 .$$

Findings:

1) During the realization of the test, the hot rolling process was conducted strictly according to the program which means that the slabs were properly warmed (no cooled spots) with prescribed rolling reduction. Therefore, at any moment has not happened braking or jamming of the rolled sheet, also the torque has not increased due to influence of the masses inertia.

2) Consequently from the previous point, for the obtained value $S_{\min}$ = 1.27 can be concluded that the available safety reserves in the critical section are small (only 27%). This lead to the conclusion that in case of additional inertia moments, the cross-section is subjected on fatigue of torsion.

3) In order to increase the level the strength characteristics, i.e. the level of the loading limit in the critical section it is needed measures to be directed with respect of changing in the cross-section design and in material quality for shafts.

Proposed solutions to increase the load limits in shaft critical section

Based on performed analysis of the possibility of structural strengthening in critical section, it is concluded that the diameter of the shaft can be increased from d_s = 512 mm to d_n = 519 mm. Also the radius of transition from d_n = 519 mm to d_n = 660.4 mm to be r_n = 30 mm (Fig. 8).

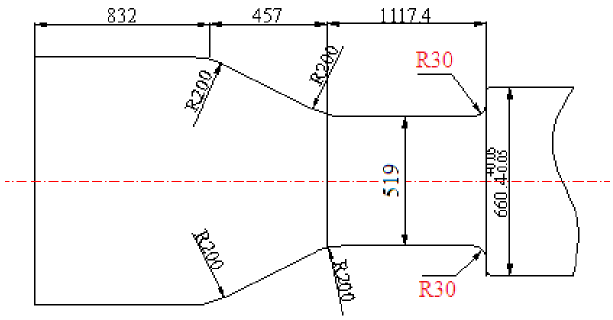

Fig. 8. Proposed changes in the dimensions of the critical section

Based on such opportunities is obtained:

1) First moment of inertia of the new critical section equals:

$$W_{0n} = 0.2 \cdot d_n^3 = 27959 \text{ cm}^3 .$$

Percentual increase of the value of the first moment of inertia in relation to the existing solution is

$$\frac{W_{0n} - W_{0S}}{W_{0S}} \cdot 100 = 4.0\% .$$

2) Based on the constructive change, the stress concentration factor in the critical section equals:

$$K_{cn} = 1 + \eta \cdot (K_r - 1) .$$

For $D / d_n = 1.29$, $\eta = 0.9$.

For $r_n/d_n = 0.0578$ and $\sigma_m > 600$ MPa, $K_n = 1.4$.

It follows:

$$K_{cn} = 1.36.$$

3) Decrease in value of the concentration factor in relation to the existing solution is

$$\frac{K_{cs} - K_{cn}}{K_{cn}} \cdot 100 = 4.41\%.$$

CONCLUSION

The overall improvement of the bearing capacity of the critical section in relation to the existing solution based on increased first moment of inertia and on the basis of reducing the stress concentration factor is:

$$\frac{T_n}{T_s} = \frac{W_{0n} \cdot K_{cs}}{W_{0s} \cdot K_{cn}} = 1.0841.$$

Based on the total enhancement, the torque limit which can be borne by the new section is:

$$T_{dr,D} = 1.0841 \cdot T_{grs,D} = 3298 \text{ kNm}.$$

The minimum safety degree in terms of the value exceeding the minimum torque limit value at permanent dynamic strength in relation of initial cracking of the outer fibers in the critical section and maximum torque measured throughout the tests of the upper shaft is:

$$S_{\min,n} = \frac{T_{rgn,D}}{T_{\max}} = 1.38.$$

By using past experiences, about the use of materials for making drive shafts can be perceived that so far for the needs of maintenance are used materials with σ_m = 664 MPa, σ_T = 479 MPa, τ_T = 368 MPa, which is considerably higher than the requirement specified in the technical documentation.

The analysis of the chemical composition and of the mechanical characteristics of the material has determined that the quality of such materials belongs to the group of carbon or alloy steels for improving, with guaranteed purity and permanent dynamic strength of torsion at variable alternate loading which equals:

$$\tau_D = 220 \div 280 \text{ MPa}.$$

If new shaft will be made with the proposed dimensions, diameter d_n = 519 mm and concentration coefficient of K_{cn} = 1.36, then the minimum torque to start the fatigue process in the outer fibers of the critical section, for shaft with permanent dynamic strength of τ_D = 220 MPa should equal:

$$T = \frac{\tau_D \cdot W_{0m}}{K_{cn}} = 4522 \text{ kNm}.$$

This value is significantly higher than the value of the torque that exceeds the dynamic strength of the working roller sleeve where $T_{\max}$ = 3667 ÷ 3960 kNm.

To ensure the bearing capacity of the shaft critical section to be always higher than the bearing capacity of the critical section of working roller sleeve, it is necessary the shaft section always be able to accept torque $T > 3960$ kNm.

1) On the basis of the activities taken during the preparation of this paper can be concluded that the determined and applied methodology gave the answers to the objectives set out in the approach.

2) In cases when enormous increasing of the rolling torque is coming out and in case of a major accident, to preserve the drive shaft from breaking and breakage to be transferred by the roller sleeve, it is needed:

2.1) To modify the dimensions of the drive shaft as follows:

– The diameter of the shaft at the critical section to be increased to d = 519 mm.

– The radius of transition in the critical section to be increased to r = 30 mm.

2.2) To replace the shaft material with material from the group of carbon or alloy steels for improving, with guaranteed purity and permanent dynamic strength of torsion at variable alternate loading to be in the range of τ_D = 220 ÷ 280 MPa.

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Original scientific paper

IMPACT OF ENERGY EFFICIENCY AND REPLACEMENT OF DIESEL FUEL WITH NATURAL GAS IN PUBLIC TRANSPORT ON REDUCING EMISSIONS OF NITROGEN OXIDES

Dame Dimitrovski, Antonio Jovanovski

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

A b s t r a c t: This paper analyzes the direct emissions of nitrogen oxides from the public transport (bus) in urban areas in the Republic of Macedonia. As influential factors on which to compare the quantity of these emissions are taken: Penetration of new (energy efficient) technologies in bus transport, the intensity of the bus fleet renewal for public transport and replacement of diesel with natural gas.

Key words: nitrogen oxides; urban transport; public transport; bus fleet; diesel fuel; natural gas

ВЛИЈАНИЕТО НА ЕНЕРГЕТСКАТА ЕФИКАСНОСТ И НА ЗАМЕНАТА НА ДИЗЕЛ-ГОРИВАТА СО ПРИРОДЕН ГАС ВО ЈАВНИОТ ТРАНСПОРТ ВРЗ НАМАЛУВАЊЕТО НА ЕМИСИИТЕ НА АЗОТНИ ОКСИДИ

А п с т р а к т: Овој труд ги анализира директните емисии на азотни оксиди од јавниот (автобуски) транспорт во урбаните средини во Република Македонија. Како влијателни фактори врз основа на кои се споредува квантитетот на овие емисии се земени: пенетрацијата на нови (енергетски ефикасни) технологии во автобускиот транспорт, интензитетот на обновување на автобуската флота во јавниот транспорт и замената на дизел-горивата со природен гас.

Клучни зборови: азотни оксиди; урбан транспорт; јавен транспорт; автобуска флота; дизел-горива; природен гас

INTRODUCTION

Apart from the direct impact of nitrogen oxides (NOx) and harmful effects on human health, it combined with atmospheric conditions (humidity, temperature, pressure...), is one of the most influential precursor to the creation of PM2.5 particles, whose concentration within previous one is much larger in winter than in summer [1].

Mobile sources are the largest emitter of NOx, due to high temperatures and the presence of nitrogen and oxygen in the combustion air and the fuel it self.

The transport sector accounts for 48% of the total emissions of NOx in 2010 in Europe.

In total final consumption of fossil fuels and biomass, transportation sector in the Republic of Macedonia accounts for 39.1% for 2011. Since all transportation subsectors and sectors, passenger transportation is most significant, with energy consumption of 470.318 kt_{oileq} or 25% of total final energy consumption of fossil fuels and biomass [2].

According to the analysis and according to the Statistics and Ministry of Interior, Republic of Macedonia has a very outdated fleet of vehicles.

Figure 1 shows the participation of buses with different age of production separated in 3 classes (not older than 5 years, not older than 10 years, and older than 10 years).

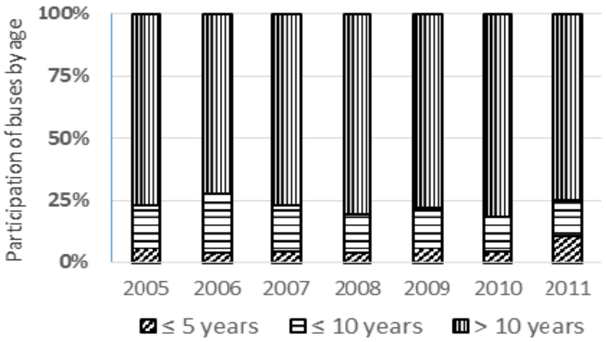

Fig. 1 Structure of bus fleet in Republic.of Macedonia, by age 2005–2011

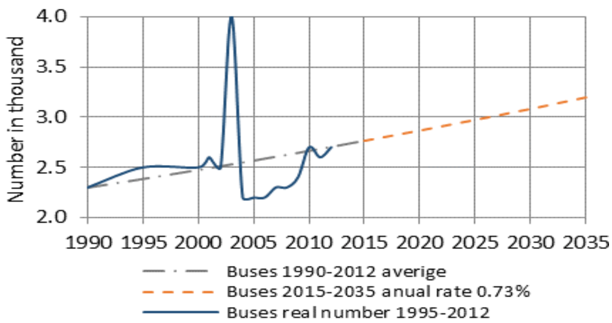

Fig. 2. Predicted number of buses in Republic of Macedonia until 2035

From the Figure 1 can be seen that for 2011 75% of the buses are old more than 10 years, while the percentage of vehicles with age less than or equal to 5 years is about 6.6% of the total registered buses for the same year.

This highlights the great impact of greenhouse gases and pollutants from this source to the environment in the Republic of Macedonia. This paper analyzes the public transport (bus-transportation) in urban areas and NO_x emissions in this sector. Here is shown the importance of the bus fleet renewal, penetration of new, efficient technologies and increased use of natural gas in transport sector for decreasing/increasing of nitrogen oxides, as one reason for excessive pollution in big cities.

SCENARIOS FOR PUBLIC-BUS TRANSPORT IN URBAN AREAS

Analyses, calculations and predictions are given in four scenarios: Development scenario 1; Development scenario 2; Pessimistic scenario 0.75; Reference scenario 1.5. The description of the scenarios is given below.

Common conditions for all scenarios

– The ratio of public passenger transport and private transport in the urban areas remain the same to 2035, which means that passenger kilometers of city buses account for 28% according total passenger kilometers.

– Trend of growth of total number of buses. According to trend growth is projected to the total number of buses in 2035 to 0.73% a year to reach that number of registered buses in thousands 3,19. (Fig. 2.)

– All demographic inputs are the same for all scenarios.

Description of scenarios

Scenario 1 predicts 4.7% growth in new buses per year of which 84% would be allocated for the replacement of old, and further 16% would be to follow the trend of growth the overall bus fleet in the Republic of Macedonia, with a reduction in fuel consumption by 1.5% per year for new buses [3]. This scenario describes the case of the use of legal measures against global producers of internal combustion engines in terms of reducing fuel consumption. Scenario 1 does not provide use of natural gas in urban bus transportation. This would happen if in the country would fall behind the development of infrastructure for natural gas, or will be under boundary conditions that would allow the development or below the recommended minimum profitability of these stations [4]. This scenario considers the option of extreme energy efficiency of new vehicles as well as government measures [5] that would drastically change the structure of the vehicle according to age in 2035 (Fig. 3).

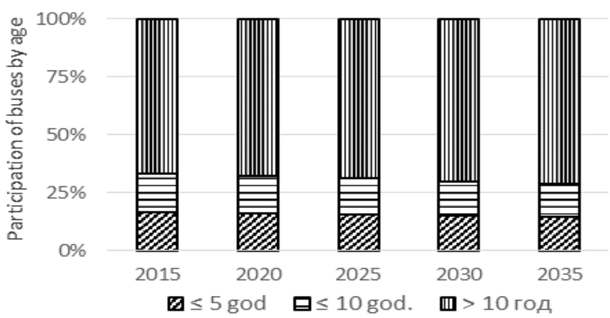

Fig. 3. Changing age structure of bus fleet from 2015 to 2035 under Scenarios 1, 2

Scenario 2 predicts 4.7% growth in new buses per year of which 84% would be allocated for the replacement of old, and further 16% would be to monitor the trend of the overall bus fleet in the country, with a reduction in fuel consumption 1.5% year on new buses. Penetration of new CNG technology in the total number of new buses would range from 1.7% (2016–2020 year) to 49% (2030–2035 year) continuous, representing some approximation of *S*-curve for acceptance of innovation [6]. This scenario envisages the development of internal combustion engines technologies of natural gas. This assumes that the efficiency of these CNG engines would have similar efficiency as that of diesel vehicles.

Pessimistic **Scenario_0.75** does not provide changes to the current trend, i.e. 3% growth in new buses per year of which 2/3 would be designed to replace the older ones, and additional third would be to follow the trend of growth of overall bus fleet in the Republic of Macedonia (Fig. 4.), and reducing the fuel consumption of 0.75% per annum. This scenario provided increased emissions of nitrogen oxides due to the decrease of efficiency of the pre- and post-treatment of exhaust gases.

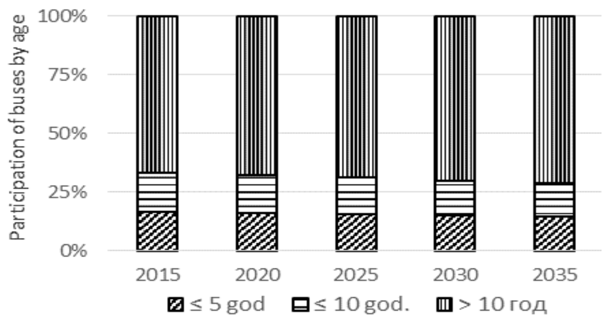

Fig. 4. Changing age structure of bus fleet from 2015 to 2035 under Scenario 0.75

Referent **Scenario_1.5** provides 3.4% growth in new buses per year of which three quarters would be designed to replace the older ones, and further quarter would be to follow the trend of growth of the overall bus fleet in the Republic of Macedonia (Fig. 5) and the reduction of fuel consumption of 1.5% per year. Penetration of new CNG technology in the total number of new buses would range from 1% (2016–2020 years) to 5% (years 2030–2035) continuously.

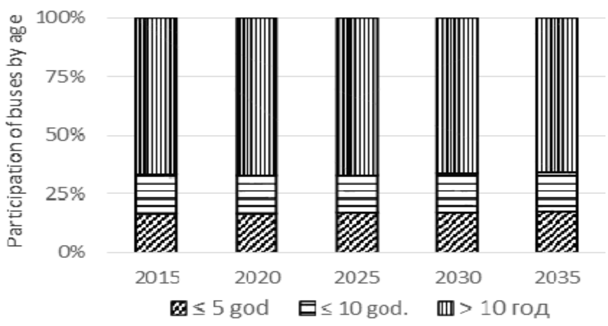

Fig. 5. Changing age structure of bus fleet from 2015 to 2035 under Scenario 1,5

MODELS FOR CALCULATION OF FINAL ENERGY AND EMISSIONS OF NITROGEN OXIDES

For assessment and prediction of fuel consumption, and emissions of nitrogen oxides from the fuels in bus passenger transport in urban areas, are used two models „MEP.MK_14" [7] and „MAED" model of the IAEA [8]. Inputs in this model are demographic factors which show direct dependence of the above sectors with the number of population, trends of population growth, concentration of population in major cities, employment rates, population structure, economic power of residents, traditions and habits. Traditions and habits are largely distinguished by commonly used passenger transport, number of passengers per passenger kilometer.

The interaction between the two models is in the factors affecting the energy needed, but MEP.MK_14 model has its own approach and sequence to the calculation of the required energy through specific data available for the Republic of Macedonia.

As influential factors that enter into the calculations of all scenarios are: passenger kilometers per year – *PKM*, number of passengers transported in one vehicle – *BP*, type of fuel with the energy contained in a unit mass of that type of fuel correlated with fuel consumption per bus, technology and efficiency of vehicles – *T* (*J*, *K*) (*J* – type of fuel with all its physical and chemical characteristics; *K* – year of introduction of the technology with a particular fuel).

From here the energy consumed in passenger transport can be presented as a function of all these parameters as input values:

$$PE = f\,(PKM, BP, T(J, K)).$$

RESULTS AND DISCUSSION

The total emissions of pollutants by a certain fuel is calculated as the sum of emissions of all pollutants from vehicles of different years of production that are located in a given year.

$$EVA.UT(\mathrm{I,J,G}) = \\ = \sum_{K=2000}^{G} VBA(G)\cdot PGA(J,K)\cdot PA(J,K)\cdot EFA(I,J,K) \qquad (7)$$

Where:

EVA.UT(*I*,*J*,*G*) (kT) – emissions by vehicles with different fuels in the year reviewed;.

G = 2011–2035 – analyzed years;

K = 2000.....G – year of manufacture of particular types of buses K ($K \leq G$);

$PA(J,K)$ (%) – percentage of buses with some fuel (J) produced in the year K;

$VBA(G)$ – number of all buses in particular year;

$PGA(J,K)$ $\left(\frac{\text{kg}}{100\text{ km}}\right)$ – consumption of fuel type (J) per one bus with year of production (K);.

$EFA(I,J,K)$ (kg/kg) – emission factors for particular pollutant (I). (I = 1...N);

N – number of treated polutants;

J = 1....M – type of fuel. (Example: J = 1 – gasoline, J = 2 – diesel, J = 3 – CNG).

Specific emissions of nitrogen oxides for all scenarios are taken from databases of GEMIS, TREMOVE and EMEP/EEA [9, 10, 11].

Figure 6 presents comparison of emissions of nitrogen oxides under all scenarios.

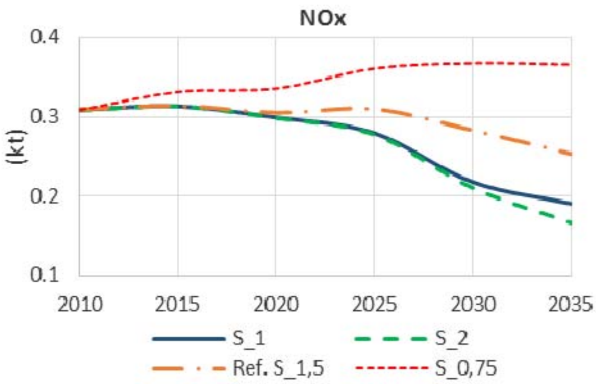

Fig. 6. Comparison of NO_x emission from buses (urban transport) under the scenarios

Best results shows Scenario 2, due to the high use of CNG. However, despite the benefits of natural gas as a fuel presented like difference between Scenario 1 and Scenario 2 they are smaller than differences in emissions between the reference scenario 1.5 and scenario 1. This clearly shows the impact of the replacement of the bus fleet and the penetration of new energy efficient technologies, as one of dominant factors in terms of reduction of nitrogen oxides.

For 2035 the differences in NOx emissions for all scenarios relative to the Reference Scenario 1.5 would be:

– Scenario 1 – 25% reduction in NOx emissions;

– Scenario 2 – 34% reduction in NOx emissions;

– Scenario 0.75 – 44% increased emissions of NO_x.

This also suggests that legal measures are essential to reducing the emissions of new vehicles regardless of fuel type. Only remains a certain ability of the fuel and technology for producing emissions below these limits [12]. Of particular importance is the treatment of exhaust gases and equipment installed in vehicles with different technologies. Natural gas vehicles are much less demanding in terms of equipment for the treatment of exhaust gases than diesel. This increases the efficiency of this type of CNG buses according diesel buses equipped with complex systems.

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Original scientific paper

PERFORMANCE ASSESMENT OF SOLAR HEATING AND COOLING SYSTEMS

Igor Šešo, Slave Armenski, Done Taševski, Dame Dimitrovski

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

A b s t r a c t: Thermal performance of the solar thermal systems are estimated using numerical methods and software since the solar processes are transitient in nature been driven by time dependent forcing functions and loads. The system components are defined with mathematical relationships that describe how components function. They are based on the first principles (energy balances, mass balances, rate equations and equilibrium relationships) at one extreme or empirical curve fits to operating data from specific machines such as absorption chillers. The component models are programed, i.e. they represent written subroutines which are simultaneously solved with the executive program. In this paper for executive program is chosen TRNSYS containing library with solar thermal system component models. Validation of the TRNSYS components models is performed, i.e. the simulation results are compared with experimental measurements. Analysis is performed for solar assisted cooling system in order to determine the solar fractions and efficiencies for different collector types, areas and storage tanks. Specific indicators are derived in order to facilitate the techno-economic analysis and design of solar air-conditioning systems.

Key words: solar air-conditioning; solar fraction; thermal efficiency; simulation

АНАЛИЗА И ОЦЕНА НА ПЕРФОРМАНСИТЕ НА СИСТЕМИТЕ ЗА ГРЕЕЊЕ И ЛАДЕЊЕ СО СОНЧЕВА ЕНЕРГИЈА

А п с т р а к т: Во овој труд е извршена оцена на термичките перформанси на системите со сончеви колектори. Притоа се користени нумерички методи и софтвери, бидејќи процесите во кои се анализира влијанието на сончевата енергија се со стохастичка природа, односно водени се од временски зависни функции. Користените компоненти во анализираните системи се дефинирани преку математички релации со кои се опишува начинот на нивното функционирање. Тие се засноваат на првиот принцип (енергетски и масен баланс, релации за рамнотежни состојби) за еден екстрем или на емпириско дефинирање на крива која го следи трендот на измерените вредности за специфичните компоненти како што се апсорпционите ладилни машини. Математичките модели на анализираните компоненети се имплементирани како подрутини, програми коишто се решаваат преку извршна програма. Во овој труд како извршна програма е избран TRNSYS, во кој е содржана библиотека со нумерички модели. Извршена е и валидација на користените компоненети од TRNSYS преку споредба на симулационите резултати со експериментално измерените. Извршената параметарска анализа кај системите за ладење топлински погонувани со сончева енергија опфаќа оцена на придонесот од сончевата енергија во вкупно потребната топлинска, како и термичката ефикасност на системот за различни видови сончеви колектори, површини и волумени на акумулациони резервоари. Добиени се специфични индикатори кои се користат при техноекономска анализа на системите кои користат сончева енергија (топлинска) за климатизација на објектите.

Клучни зборови: сончеви колектори; климатизација; придонес од сончева енергија; термичка ефикасност; симулација

INTRODUCTION

Reduction of fossil fuel consumption and harmful emissions to the environment could be reduced by implementing the solar energy in heating and cooling of the buildings. It is well known that in the European Union more than 25% of the total energy consumption is due to buildings with heating and cooling representing a major percentage. In the EU-32 countries the final energy consumption in 2003 for heating and cooling the buildings represented about 3600 TWh with 93% for heating and only 7% for cooling [1]. But a tremendous increase in the market for air-conditioning can be observed worldwide especially in developing countries such as Macedonia. On Figure 1 are presented the sales rates for room air-conditioners (RAC units) in different regions of the world (blue representing worldwide sales and green one European ones). In 2002 were sold 44 milion units worldwide and more than 94 million units in 2012 (source by Japan Air-Conditioning & Refrigeration News 2013). In order to limit the negative impact on the energy consumption and on the electricity network management, new environmentally sound concepts are of particular importance.

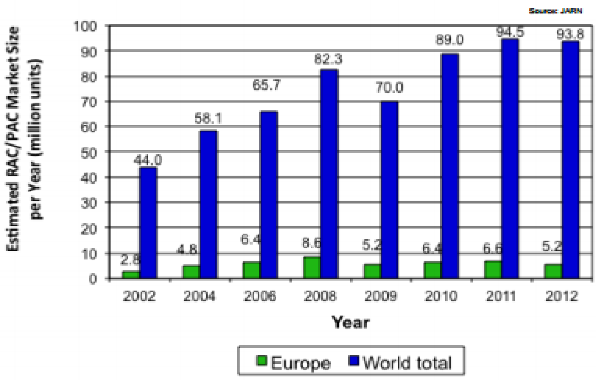

Fig. 1. Evolution of air-conditioning market worldwide

Energy consumption in Europe is expected to face an increase within the next 30 years. This is due the climate and comfort requirements, architecture and technical equipment of larger, commercial buildings require more and more cooling. Space cooling is moving quickly from luxury into necessity and represents a fast growing market. The rise in cooling demands is due to more reasons such as: greater comfort expectations, the perception that cooling contributes to higher productivity and the increase of internal loads of electronic equipment.

By 2020 all new and refurbished buildings should be near zero energy. So the cooling demand will have to decrease. But this means as well that a massive use of renewable energy sources will have to be done.

Building air-conditioning is today based mainly on electrically driven mechanical vapour compression technologies. In [2] R. Ciconkov performed survey on refrigerating and air-conditioning systems regarding the use of CFS fluids in Macedonia Although for new developed predominately large capacity scale developments it is reported about high efficiencies in the compression cycle, for the standard air-conditioning in existing buildings can be assumed that on an average less than 3 kWh 'cold" are produced with the electricity input of 1 kWh_{el}. Subsequently this implies that 1 kWh primary energy is used for the provision of 1 kWh useful cooling energy. Until now mostly the electrical peak loads were occurring during the winter period, but now are shifting to the summer months and challenging capacity limits and therefore increasing the need of solar cooling technology even in Europe. In [3] is examined TEWT concept for estimating of the global warming from refrigerating and air-conditioning systems.

Solar technologies can supply the energy for all of the building's needs – heating, cooling, hot water, light and electricity, without the harmful effects of greenhouse gas emissions created by fossil fuels thus solar applications can be used almost anywhere in the world and are appropriate for all building types.

Solar thermal systems for hot water production are already mandatory in new buildings according to solar ordinances for example in Spain [4], Portugal, Italy, Greece and other European countries [5].

It is very logical to apply solar energy for cooling purposes since in many applications, such as air-conditioning cooling loads and solar gains are more or less in phase on daily time basis. Thermally driven cooling was applied within last decades in niche-markets preferably in the large capacity scale range, using waste heat or heat from combined heat and power production. A survey made on the basis of IEA Task 38 and Task 48 work has shown the estimated number of installation worldwide nearly of 600 systems in 2010 and nearly 1000 systems in 2012.

In 2013, Solar Air-Conditioning is more than ever representing a huge potential of development for solar energy but this promising technology is facing one man issue, a general lack of economic competitiveness – as it is still the case for many renewable energies unless incentives are in place.

SIMULATION TOOL FOR SOLAR ASSISTED AIR-CONDITIONING SYSTEM

In order to assess the performance of the solar air-conditioning system under weather conditions for Macedonia, simulation model is developed for solar assisted air-conditioning system applied in residential building.

Simulation in solar cooling and air-conditioning is possible at different levels. A classification may be made by sorting the tools into:

- materials level: analyzing the effect of e.g. different sorption materials on the sorption process;
- component level: detailed analysis of a system component, e.g., chillers, cooling towers, etc.;
- process quality level: theoretical analysis of various processes;
- detailed system simulation for optimizing control strategies.

Few simulation programs for planning support and sizing of solar assisted air-conditioning systems exist. Also some more programs used internally may exist; additionally, more commercial simulation platforms like Matlab/Simulink, Modelica etc. can be used, but do not provide of a sufficient number of components for modeling a complete solar air-conditioning system yet.

In this paper is used TRNSYS simulation software and the TESS library for the system component numerical models.

TRNSYS is a commercial time step simulation tool worldwide available. High flexibility in the choice and arrangement of the system components, the desired system can be constructed by selecting and connecting the individual components and by defining the system control. Own written ‘types‘ (component models) may be added. Once the time step of the simulation is chosen, it is constant during the simulation run. A major advantage of the program is the availability of a building model, which can be edited in a special building editor and allows the calculation of building loads.

SYSTEM DESCRIPTION

Up to now, existing SHC prototypes were mostly designed on an empirical basis. For small-size systems, simple layouts are generally preferred, in order to improve the reliability and reduce the capital cost of the plant. For example, fixed-volume pumps are selected, and a gas-fired heater is used as the only auxiliary device. For large-size plants, more expensive but also more efficient components can be taken into consideration, such as variable-speed pumps and auxiliary electric chillers. In any case, the main choices to be taken when designing the layout of a SHC system concern: (i) the type of solar collectors; (ii) the thermal-driven chiller (for example, absorption or adsorption machine); (iii) the auxiliary system for cooling and heating have been developed.

Usually, SHC systems are based on absorption chillers, since the commercial availability of adsorption chillers is very scarce. In addition, adsorption chillers are only available for small cooling capacities, and their cost is significantly higher than for absorption chillers. Thus, most of the SHC prototypes installed all over the world are equipped with an absorption chiller. Single-effect absorption chillers are usually adopted, since double-effect devices must be supplied with an hot stream at temperature higher than 150 °C, that would involve the use of concentrating solar collectors [6]. Such configuration – high temperature solar collectors and double-effect chillers – is obviously interesting from an energetic point of view, but is presently too expensive to be considered in pre-commercial applications. Thus, the most common configuration is based on the coupling of evacuated-tube solar collectors with single-effect absorption chillers. In particular, LiBr–H_2O models are commonly preferred, since H_2O–NH_3 chillers require higher temperatures for the inlet hot stream, and in addition handling ammonia can be somewhat dangerous. For such arrangement, three different system layouts were investigated in this paper, whose characteristics and working principles are briefly summarized in the following:

The model, i.e. analyzed system, generally consists of four main subsystems:

1. The first subsystem is composed of solar collectors with complete hydraulic fittings and control – differential controllers, plate heat exchangers, i.e. this system is represented the source of thermal energy for heating or thermal energy for driving the cooling the absorption machine.
2. Second is the subsystem for hot and cold storage which includes the storage tanks for hot/cold water that actually represents the connection between the heating system in the building, i.e. absorption cooling machine and the source of heat.
3. The heating system introduced with heating/cooling devices, hydraulic components, heat exchangers, cooling absorption machine and eventually existing conventional sources of heat and/or cooling energy.
4. The fourth subsystem is the consumer of thermal energy, i.e. the building. This system is represented by the thermal characteristics of the object, i.e its orientation in space.

On Figure 2 is presented analyzed, i.e. modeled and simulated solar assisted air-conditioning system. The main system components are: the solar collector array, two storage tanks, auxiliary heater, absorption chiller and the energy consumer i.e. the building which also incorporates the heating/ cooling system components.

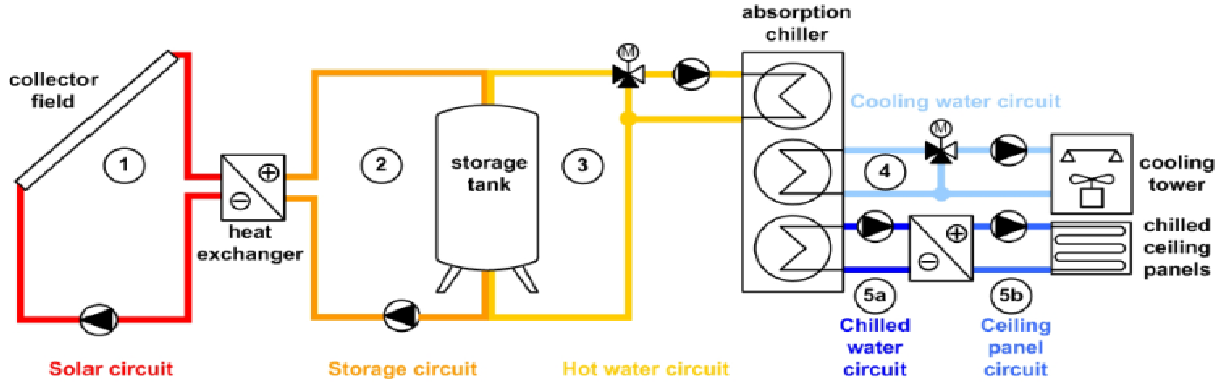

Fig. 2. Functional scheme of the system

In the analyses are considers vacuum tube and flat plate collectors product of Camel Solar, type: CS Full Plate 2.0-4 and Vacuum CS 10. The thermal performance of the solar collectors are given in their solar key mark certificate.

At the simulated building internal heat gains are consider by the lighting power density 5 W/m^2 and home appliances with specific power of 2 W/m^2. The absorption chiller condenser is connected to the wet cooling tower product of Baltimore AirCoil type PF2-0406AA-31-3. Numerical modeling of the cooling tower is provided by the TRNSYS Type 510 model from Tess library, a closed circuit cooling tower which cools the liquid stream by evaporating water from the outside of coils containing the working fluid. The working fluid is completely isolated from the air and water in this type of system.

The cooling system in the building is represented with ventilation air distribution system. The heat exchange between the chilled water from the absorption chiller and the ventilation air is provided with heat exchanger water-air modeled Type 508a which is a cooling coil modeled using a bypass approach in which the user specifies a fraction of the air stream that bypasses the coil. The remainder of the air stream is assumed to exit the coil at the average temperature of the fluid in the coil and at saturated conditions. The two air streams are remixed after the coil. Chilled water flow from the absorption chiller to the cooling coil is set to 2900 kg/h and the air flow rate to the building is 4000 kg/h. The auxiliary heater power is modeled 12 kW and the outlet temperature is 80 °C, which is the absorption machine driving temperature.

System component models definition and validation

Validation is performed for the basic solar thermal system components: solar collector, storage tank and differential controller. The experimental system consists of: flat plate solar collector with area of 2 m^2, connected with the internal heat exchanger of the storage tank. Control is provided by differential controller which is set to turn the circulation pump on, when the temperature difference between the collector outlet temperature and the tank temperature is greater than five. There is no consumption of hot water from the storage tank, i.e. the only heat transfer is with the surroundings. The circulating pump is set to maintain fluid (water) flow rate set to 7,5 lit/min.

Measurements are made on at an hour interval for the fluid inlet T1 and outlet T2 temperatures from the solar collector, tank fluid temperature T3 and the solar radiation is measured with the pyrometer S as presented on Figure 3. The experimental setup of the analyzed solar thermal system is located in Skopje, R. Macedonia, northern latitude of 42° and 21°43′ east longitude. Temperature measurements are performed with temperature data logger thermocouple probes type K.

Solar collector type is evacuated tubular direct flow, product of Camel Solar type Vacuum CS 15 Solar KeyMark certified. During the measurements it was placed under tilt of 45°, south orientated, i.e. azimuth angle of 0°. The collector thermal performance test results according EN 12975 are presented in Table 1, while the storage tank technical data are given in Table 2.

In the TRNSYS model solar collector is model with the Type 538 from the Tess library and technical data from Table 1.

The storage tank is modeled with the Type 60d including the internal heat exchanger for which are supplied data from Table 2. Type 2b-2 is used to simulate the differential controller set with upper dead band of 5 and lower dead band 2, the high limit cut-off temperature set to 100 °C. Between the solar collector and storage tank is connected pipe Type 31 modeled with internal diameter 0.0025 m, length of 10 m and loss coefficient of 0,3 W/m^2K to account for the heat losses. The pipe network modeled with Type 31 is used to increase the thermal capacity of the system and thus increase the simulation stability. Circulating pump is represented with the component Type 3d with mass flow rate 450 kg/h, i.e. 7,5 l/min same as in the experimental setup (Figure 2).

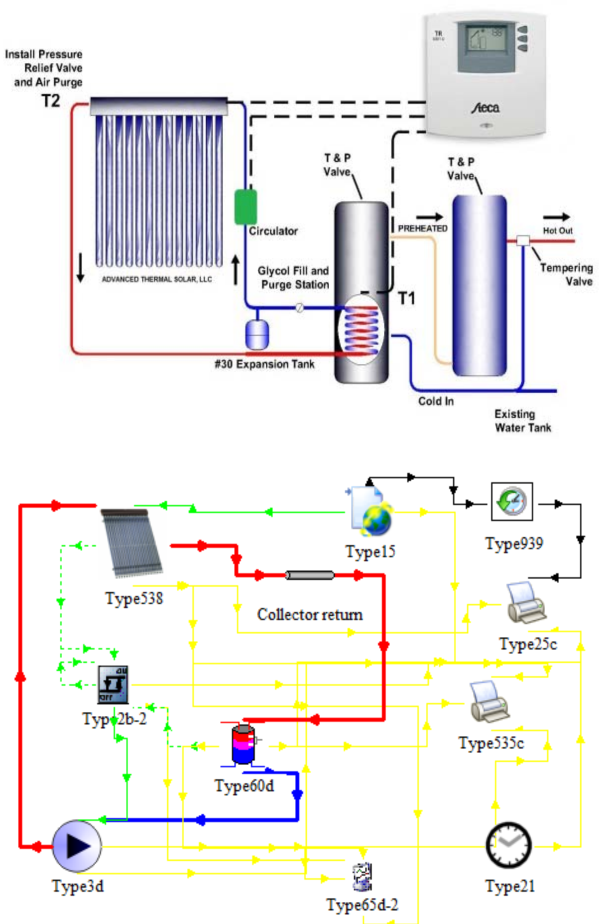

Fig. 3. Solar system experimental and simulation scheme

Table 1

Technical data for collector type Camel Solar Vacuum tube SC 15 ("U" type)

Technical data	Unit	Dimension
Dimensions $L \times W \times H$	mm	1990×1180×158
Absorption	/	0.92–0.96
Emittance	/	0.04–0.06
Dimension absorpber tubes	mm	8×0.4 (U pipe)
Number of absorber tubes	/	15
Outer diamter glass tube	mm	58
Transmittance		0.92
Nominal flow rate per collector	kg/h	90
Conversion factor, $F(\tau\alpha)en$	/	0.695
Angle modifier, b_o	/	0.138
Optical efficiency, η_o	/	0.738
Heat transfer coefficient, a_1	W/m^2K	1.725
Coefficient, a_2	W/m^2K^2	0.01
Diffuse angle modifier, $K_{\theta d}$	/	1.203
Incidence modifier, $K_\theta = 50°$	/	0.935
Area related heat capacity, c	kJ/m^2K	58.4
Volume flow rate	l/m^2h	72
Apperture area per collector unit	m^2	1.42

Table 2

Storage tank technical details

Technical data	Unit	Dimension
Capacity	l	150
Height, H	mm	1210
Diameter, D	mm	560
Insulation, rigid PU	mm	50
Coil capacity	l	4.56
Heat exchanger surface	m^2	0.74
Prolonged power according DIN 4708 80 / 60/45	kW m^3/h	25 0.61
NL-power coefficient at 60°C	–	2.5
Coil outlet, L	mm	202
Cold water inlet, A	mm	202
Sensor sleeve for thermostat, G	mm	822
Coil inlet, K	mm	592
Hot water outlet, E	mm	868

Measurements are performed starting from date 18.09.2013 until 28.03.2014 and in parallel are measured two systems with same capacity storage tank of 150 liters but different type of collector's, i.e. flat plate and vacuum tube solar collectors. Validation process use data for the vacuum tube collector and the results are presented only for one day period (18. 09. 2013) with collection time interval ranging between 20 min and 45 min interval, from 10:40 up to 16:05 h.

According above presented data, i.e. diagrams can be concluded that there is acceptable match between the measured and simulated results (Figures 4, 5 and 6). The discrepancies between the measured and simulated results are expected since the solar radiation has different values, i.e. simulated values are taken from the Meteonorm database for the selected location, while the measure are obtained directly for the specif loactioin as given on Figure 7.

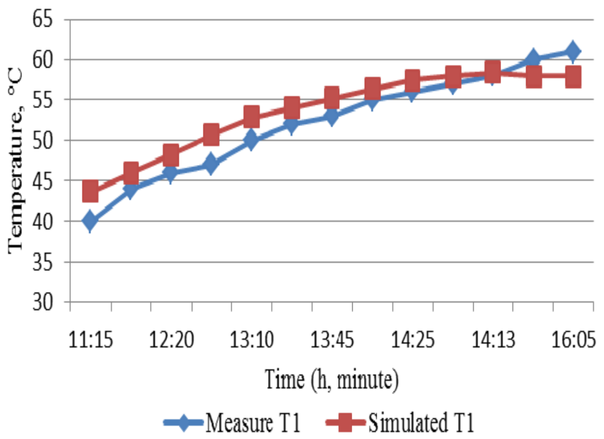

Fig. 4. Measured and simulated results for the collector inlet temperature

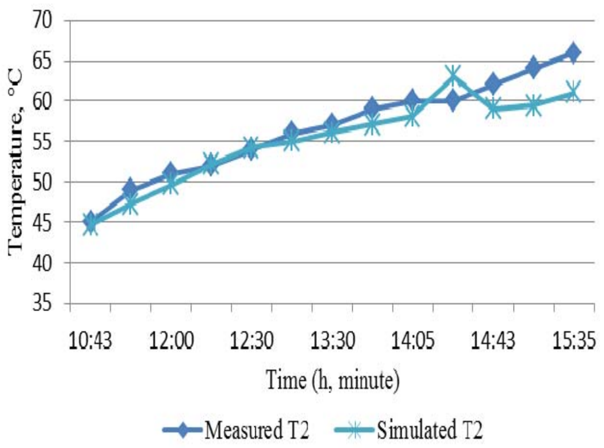

Fig. 5. Measured and simulated temperatures at the collector outlet

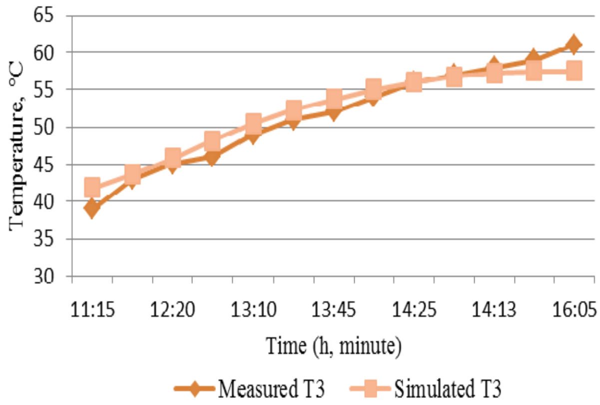

Fig. 6. Measured and simulated temperatures inside storage tank

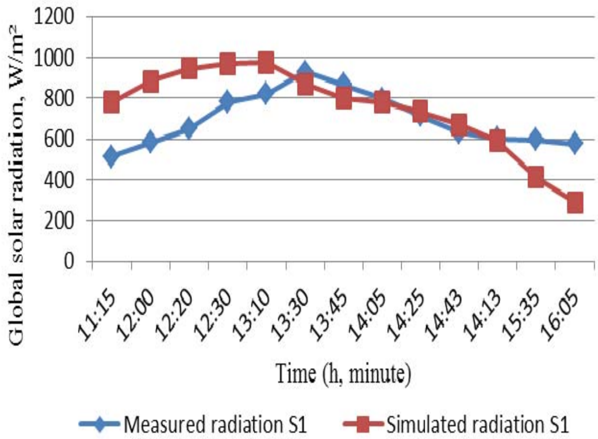

Fig. 7. Hourly measured and simulated solar radiation for the specific day

Another influencing factor is the uncertainty of the measurements error and last but not the least it should not be neglected the transition nature of the solar thermal systems.

The resulting simulations reveal the individual thermal behaviour of the solar collector, storage tank, differential controller and circulating pump as well as their assembled thermal behaviour. These results coincidence with the respective experimental data, thus this fact validates these models for future application in the heating/cooling system.

Validation for the absorption chiller is performed for the TRNSYS component Type 177.

This component type offers four numerical modes of absorption chiller. In this simulation is used mode "a", i.e. Type 177a which is standard mode using user supplied characteristic parameters. Since in this paper are considered only solar air-conditioning for residential buildings, in Table 3 are given the technical data for several small absorption chillers. From the presented absorption chillers, in the simulation is modeled the absorption chiller $H_2O/LiBr$ produced by Sonnenklima type Suninverse 10. Simulation of the absorption chiller is done with the component Type 177a, whereas input parameters are used the values for Suninverse provided in Table 3. As output for the absorption chiller cooling power is obtained 10,1 kW, which corresponds with the factory value. Validation exists for the Type 177 mode "d" performed by Albers and Ziegler [7], using the measurement results from Kühn [8]. According to this, final conclusion is that this numerical model of absorption chiller provides reliable results, thus it is suitable to be used as model for further simulations.

Table 3

Technical data for market available small capacity absorption chillers

Company	Yazaki	EAW	Sonnenklima	Rotarica
Product name	WFC-SC5	Wegal SE 15	Suninverse 10	Solar 045
Technology	Absorption	Absorption	Absorption	Absorption
Working pair	$H_2O/LiBr$	$H_2O/LiBr$	$H_2O/LiBr$	$H_2O/LiBr$
Cooling capacity, kW	17.6	15	10	4.5
Heating temperature, °C	88/83	90/80	75/65	90/85
Recooling temperature, °C	31/35	30/35	27/35	30/35
Cold water temperature, °C	12.5/7	17/11	18/15	13/10
COP	0.70	0.71	0.77	0.67
Dimensions (W×D×H), m	0.60 × 0.80 × 1.94	1.75 × 0.76 × 1.75	1.13 × 0.80 × 1.96	1.09 × 0.76 × 1.15
Weight, kg	420	660	550	290
Electrical power, W	72	300	120	1200 (incl.fan)

PERFORMANCE ASSESMENT OF THE SOLAR AIR-CONDITIONING SYSTEM

It has become recognized that, however, solar heating is the product of a collection of components comprising a system and needs to be studied such. Because of the interactions of components, optimal system performance occurs under conditions different from those for optimal behaviour of each component. For example, optimal collection efficiency would not necessarily be coupled with least auxiliary energy.

Many different hydraulic schemes are designed which makes difficult to compare the installations performances [9]. Methods used to determine solar heating and/or cooling energy requirements for both active and passive/hybrid systems are described by Feldman and Merriam, Hunn, Nowag and other. For thermally driven systems the scheme on Figure 8 is used to identify main components and energy flows of the system. On Figure 8 is presented small scale system for family houses, small multidwellings, using a small size packaged ab/adsorption solar system. This configuration is an adaptation of the solar combi system including the cooling function is also called SSC + Solar Combi.

There are four generally accepted measures of solar system performance:

- *Collector efficiency* applies to the performance of the solar energy collection subsystem. It is the energy collected, divided by the radiation incident upon the collectors. Influence of the collector position on the collec to thermal efficiency is done in [10].
- *System efficiency,* or solar heating performance factor, is the solar heat delivered to the load divided by the total radiation incident upon the collector.
- *Solar fraction* is the fraction of the total heat requirement that is met by solar energy.

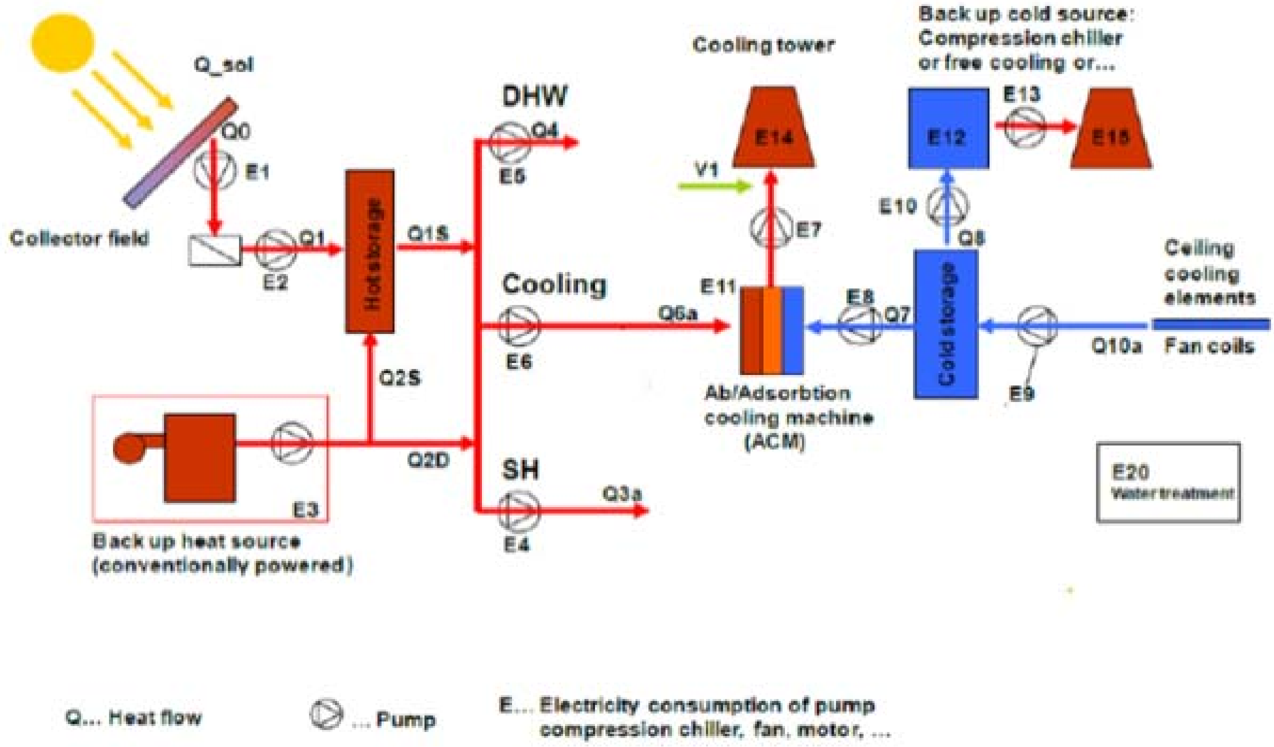

Fig. 8. Components and energy flows for solar air-conditioning system

Electrical coefficient of performance is the solar heat delivered to the load, divided by the electrical energy used to operate the system.

Each solar system operates at characteristic efficiency level resulting from the interaction of the subsystems, environmental conditions and system configurations. The net savings per square meter of solar collector indicate the relative performance of each of these systems.

The five categories of system-level design parameters that limit solar system performance.

- *Solar resource assessment.* This category represents the solar reference weather data values used by the solar design community.
- *Collection subsystem*. This category represents the solar collection sub-system, including devices used to capture incoming solar radiation.
- *Storage subsystem.* This category deals with all aspects of the system effects caused by storage components.
- *Controls.* This category refers to equipment and methods for controlling solar components within the solar system.
- *Load.* This category deals with the types and magnitude of the heat requirements in the buildings.

REFERENCE BUILDING MODELLING AND SIMULATION

Building as energy consumer has a major impact on the overall efficiency of the solar system, i.e. can be simply said that the building itself is one of the leading parameter in sizing the system. Since the analyses are made for climatic conditions in Macedonia also the thermal performance of buildings must be in accordance with the Regulations on energy efficiency in Macedonia. Furthermore the analysis is taken into account the impact of the specific consumption of heating/cooling energy of the building (kWh/m^2)/a to the response and the performance of the solar collector system.

Main governing indicators according to which is based the system comparison are: thermal efficiency of solar collectors, solar fraction and power consumption for the auxiliary devices.

In Table 4 are listed three "types" of the building, i.e. physically is the same building only the insulation thickness on the external walls, roof and floor are varied in order to obtain different values for specific annual heat. The main idea for this analysis is to assess the influence of the thermal performance of buildings on the economic viability of the use of solar thermal systems in air-conditioning.

Table 4

Reference building physical and thermal performance data

Surface	Orientation	Surface, m²	Building I	Building II	Building III
			U, W/m²K		
Out.wall 1	North	42	0.58	0.33	0.18
Window 1	North	3	1.4	1.4	1.4
Out.wall 2	East	25.5	0.58	0.33	0.18
Window 2	East	4.5	1.4	1.4	1.4
Out.wall 3	West	25.5	0.58	0.33	0.18
Window 3	West	4.5	1.4	1.4	1.4
Out.wall 4	South	42	0.58	0.33	0.18
Window 4	South	3	1.4	1.4	1.4
Floor	–	150	0.33	0.33	0.24
Roof	–	150	0.54	0.42	0.35
Window type		Double glazed TRNSYS library (w4-lib data)			
Window solar heat gain coefficient, g			0.589		
Out.wall construction	2×Plaster 2 cm, brick 25 cm		Insulation 5 cm	Insulation 10 cm	Insulation 20 cm
Floor	Granite tile 6 cm, cement mortar 5 cm, concrete slab 20 cm		Insulation 10 cm	Insulation 10 cm	Insulation 15 cm
Roof	Concrete slab 20 cm, hydroisolation, cement mortar 5 cm		Insulation 10 cm	Insulation 10 cm	Insulation 15 cm
Convective coefficient – outside			α_n = 25 W/m²K		
Convective coefficient – inside			α_v = 7.7 W/m²K		

Constant value of 0.3 1/h is defined for the infiltration of outdoor air, while for the summer when cooling is required in the building is envisaged/modeled mechanical ventilation defined with air mass flow and temperature entered through \the models of fan and heat exchanger air-water which is directly connected with the cooling absorption machine.

Regarding the thermal comfort, in the heating mode the inside temperature is defined to be 20 °C from 05:00 to 22:00 and for the rest is defined set-back temperature of 16 °C, for the cooling mode is defined constant inside temperature of 26 °C.

Building I has 90 (kWh/m^2)/a, Building II with 70 (kWh/m^2)/a, and Building III has 57 (kWh/m^2)/a. Comparing the energy consumption Building III has 42% lower than Building I and 19% than Building II.

SYSTEM SIMULATION RESULTS

The performance of future conventional space-conditioning systems affects the economic potential of active solar systems. The performance and cost of today's conventional heating, cooling and domestic hot water system can be readily determined, but conventional heating and cooling-technology is constantly improving

In the analysis for the heating considered two reference: Buildings type II and III (as given in Table 4), with specific heat energy consumption of 70 and 57 (kWh/m^2)/a respectively. In the analysis for the cooling is considered only Building type III which has specific cooling energy of 12 (kWh/m^2)/a. The time step used in the simulations is 7,5 min and the heating and loads are integrated on hourly basis. On Figure 6 are presented the results from the simulation of solar assisted heating with flat plate collectors varying their total area 16 m^2, 32 m^2, 64 m^2, mass flow rates are 50 kg/h m^2 and heat storage tank of 1000 and 2000 litres only for the 64 m^2 collector area. Collectors are tilted 40° toward south – azimuth 0° also is installed 200 litres DHW storage tank heating with the same collector array only in period when the heating storage tank is charged or the condition for the circulation pump is not satisfied.

Common for the analyzed systems is that in each of them the heat is distributed through the underfloor heating with flow rate of 2000 kg/h, solar collector array mass flow rate depending from the collector area, i.e. 50 kg/h m^2, auxiliary heat energy is provided by heater located at the fluid tank outlet with capacity of 12 kW connected with the generator of the absorption cooling machine and 9 kW for the DHW installed also at the tank hot water outlet set to maintain constant temperature of 45 °C.

From the obtained results it is concluded that there are no large differences between the solar collector yield of 32 m^2 and 64 m^2. This is result of the small storage tank capacity which cannot store the available heat from the 64 m^2 collector array solar/heat yield resulting in storage temperature increase thus decrease in solar fraction and collector efficiency. On Figure 9 are presented hourly values of the building heating loads and collector yields.

Since the results on Figure 9 are very dense cause of the hourly values thus cannot be easily noticed the differences, therefore on Figure 10 are also presented collector yields only for ten days.

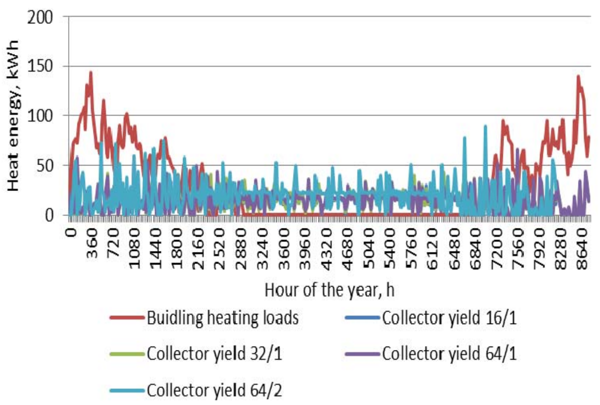

Fig. 9. Hourly heating loads and collector's useful energy in funtion of different collector array areas storage tank volume

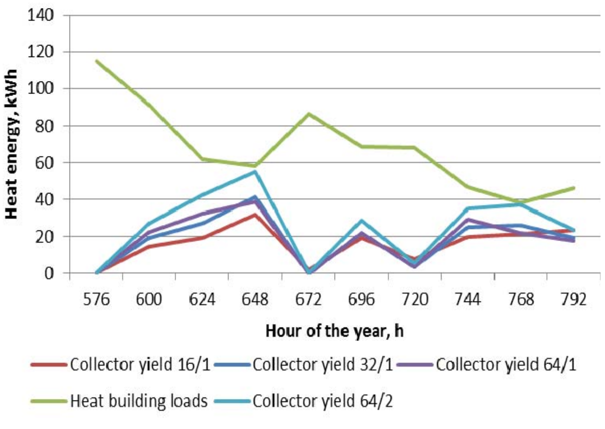

Fig. 10. Hourly heating loads and collector energy yield for different areas for ten days period

In Table 5 are presented results for delivered heating energy, annual heating energy cost, system price and the environmental indicator – CO_2 emissions, for conventional heating systems with heat sources: electrical energy, wood pellets and heat pump. For the heat pump COP is assumed averaged yearly value of 3.

Parametric analysis considers combinations between solar thermal systems and auxiliary heating devices, compared with the performance of the conventional heating system with electrical boiler or heat pump. The analyzed solar systems have total solar collector area of 16 m^2, 32 m^2 and 64 m^2 combined with storage tanks of 1000, 1500 and 2000 litres, and auxiliary heating energy provided by electric heater or heat pump air-water with E.V.I compressors with nominal capacity of 15 kW product of Hydros model Lzti 10.

Within Table 6 and Table 7 are summarized the results from the parametric analysis of systems in regard of different: collector area, storage tank volume and auxiliary heat source type, i.e. Electric Heater or Heat Pump.The assessment of the performance is done for heat energy consumption, annual energy, system costs and environmental impact indicator presented by the value for the annual CO_2 (kg/year) annual emissions.

In Tables 6 and 7 can be noticed that the auxiliary energy for the DHW is same as for systems with same collector area and storage tank volume. This is due to the fact that the heat energy provided from the electric heater or the heat pump are dedicated only for the absorption chiller while the DHW tank has independed electric heater installed at the outlet of the hot water. Further are the results from the same energy and environmental analysis for the building with specific energy consumption of 57 (kWh/m^2)/a, presented in Table 8 and Table 9. Beside the energy and environmental data also are presented economic data/indicators such as system investment costs and estimated annual energy costs

These economic parameters provides a better insight for the system feasibility and thus possibility for implementation in practice.

With Figure 11 graphically are presented the results from the simulation for primary energy consumption for various solar system configurations in regard of building specific heat energy consumption.

The results for the heat and primary energy savings are obtained in comparison to heating system with electrical boiler as heat source.

Table 5

Annual energy and environmental indicators for building with specific heat consumption 70 (kWh/m^2)/a

Parameter	Unit	El. boiler	Pellet boiler	Heat pump
Heat power	kW	12		
Annual delivered heat energy	kWh	13103		
Average thermal efficiency/COP	–	0.99	0.91	2.5
Annual consumed energy	kWh	13235	14399	5241
System electrical energy consumption (circ.pumps)	kWh	144		
Annual CO_2 emissions	kg/year	12177	58	1730

CO_2 emissions and primary energy consumption factors are provided from the standard “Energy performance of buildings – Overall energy use and definition of energy ratings” EN 15603_2008 [11].

Table 6

Solar thermal system energy and environmental performance indicators for building with specific heat energy consumption 70 (kWh/m^2)/a – part 1

Parameter	Unit	16/1000-EH	16/1000-HP	32/1000-EH	32/1000-HP	64/1000-EH	64/1000-HP	32/1500-EH
Auxiliary energy – heating system	kWh	8550	8550	7420	7420	6466	6466	6996
Auxiliary energy – DHW	kWh	750		562		428		639
System electrical energy consumption (circ. pumps)	kWh	144	144	114	114	90	90	130
Specific electrical energy price	eur/kWh	0.09						
Total energy price	Eur	850	348	729	300	629	256	640
Heat source device/system price	Eur	3600	7000	6000	10500	10000	14700	7000
Primary energy consumption	kWh	28777	12790	26798	10946	23117	9426	25702
Annual CO_2 emissions	kg/year	3069	1275	2672	1091	2305	940	2562
Annual average solar fraction – SF	–	0.19		0.30		0.39		0.34

Ref. building 70 (kWh/m²)/a; Solar thermal system – l. Area/Storage tank volume – EH (electric heater) ; HP (heat pump)

Table 7

Solar thermal system energy and environmental performance, for building with specific heat energy consumption 70 (kWh/m^2)/a – part 2

Parameter	Unit	32/1500-HP	64/1500-EH	32/1500-HP	32/2000-EH	32/2000-HP	64/1000-HP	32/1500-EH
Auxiliary energy – heating system	kWh	6996	5830	5830	7250	7250	5921	5921
Auxiliary energy – DHW	kWh	639	490					
System electrical energy consumption (circ. pumps)	kWh	130	103	103	138	138	111	111
Specific electrical energy price	eur/kWh	0.09						
Total energy price	eur	287	578	237	665	273	543	223
Heat source device/system price	eur	11500	12000	16500	8000	12500	12800	16700
Primary energy consumption	kWh	10539	21260	8709	24454	10054	19966	8207
Annual CO_2 emissions	kg/year	1051	2120	868	2438	1003	1991	818
Annual average solar fraction – SF	–	0.34	0.45		0.32		0.44	

Ref. building 70 (kWh/m²)/a; Solar thermal system – l. Area/Storage tank volume – EH (electric heater) ; HP (heat pump)

T a b l e 8

Solar thermal system energy and environmental performance indicators for building with specific heat energy consumption 57 (kWh/m^2)/a – part 1

Parameter	Unit	16/1000-EH	16/1000-HP	32/1000-EH	32/1000-HP	64/1000-EH	64/1000-HP	32/1500-EH
Auxiliary energy – heating system	kWh	6708	6708	5762	5762	5418	5418	6192
Auxiliary energy – DHW	kWh	713		527		402		595
System electrical energy consumption (circ.pumps)	kWh	139	139	109	109	86	86	115
Specific electrical energy price	eur/kWh	0.09						
Total energy price	eur	680	280	576	239	532	217	567
Heat source device/system price	eur	3600	7000	6000	10500	10000	14700	7000
Primary energy consumption	kWh	22664	10285	21177	8687	19549	7990	22846
Annual CO_2 emissions	kg/year	2449	1025	2111	866	1949	797	2278
Annual average solar fraction – SF	–	0.22		0.33		0.39		0.28

Ref.building 57 (kWh/m²)/a; Area/Storage tank volume – EH (electric heater) ; HP (heat pump)

T a b l e 9

Solar thermal system energy and environmental performance indicators for building with specific heat energy consumption 57 (kWh/m^2)/a – part 2

Parameter	Unit	32/1500-HP	64/1500-EH	64/1500-HP	32/2000-EH	32/2000-HP	64/2000-EH	64/2000-HP
Auxiliary energy - heating system	kWh	6192	5600	5600	5074	5074	4042	4042
Auxiliary energy - DHW	kWh	595	457		630		488	
System electrical energy consumption (circ. pumps)	kWh	115	94	94	118	118	97	97
Specific electrical energy price	eur/kWh	0.09						
Total energy price	Eur	255	554	227	524	216	416	172
Heat source device/system price	Eur	11500	12000	16500	8000	12500	12800	16700
Primary energy consumption	kWh	9367	20360	8331	19271	7943	15315	6319
Annual CO_2 emissions	kg/year	934	2030	831	1921	792	1527	630
Annual average solar fraction – SF		0.28	0.36		0.41		0.53	

Ref.building 57 (kWh/m²)/a; Solar thermal system – Area/Storage tank volume – EH (electric heater) ; HP (heat pump)

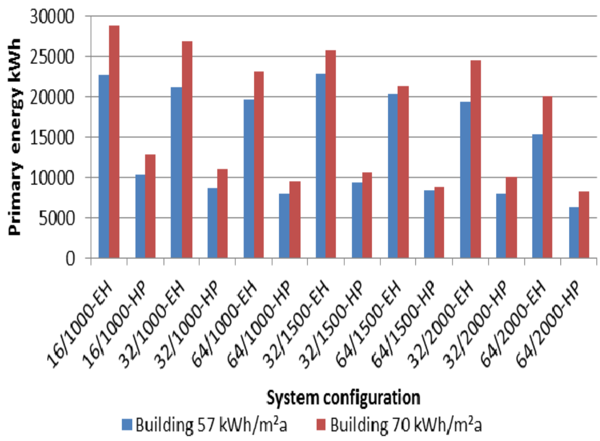

Fig. 11. Primary energy consumption
*Total solar collector area/storage volume – **E**lectric **H**eater (**H**eat **P**ump)

Further are analyzed system performances when is in cooling mode. The building has specific cooling energy consumption of 12 (kWh/m^2)/a, i.e the total annual cooling load is 1800 kWh. Results from the analysis are presented in Table 10.

The performance data for absorption cooling machine are obtained from the manufacturer Sonnenklima type Suninverse 10. The chiller average cooling coefficient of performance is averaged on 3. The DHW in the case of conventional chiller is heated 100% by electrical heater while in the case of absorption machine, area of solar collectors are sufficient to provide 100% solar fraction for the DHW, i.e. it is not used any additional auxiliary energy.

The cooling period considers four months starting from June until September and the inside temperature is set to be constant 26 °C.

According the presented results it is obvious that solar-assisted cooling system provides big possibilities for reduction in primary energy consumption and CO_2 emissions. But still from simple analysis, i.e. according the economic indicators, payback period would be bigger than 20 years bringing the feasibility of the system in question. Main reasons for the non-feasibility of these solar-assisted air-conditioning systems mainly is the low electricity price of 0.09 eur/kWh but also is the low cooling energy demand since it is analyzed residential building which usually have small internal gains.

Table 10

Solar thermal system energy and environmental performance for building with specific cooling energy consumption 12 (kWh/m²)/a

Parameter	Unit	Chiller	10/1000-EH	14/1000-EH	16/1000-EH	18/1000-EH	22/1000-EH
Auxiliary energy – cooling system	kWh	600	324	246	204	174	132
Auxiliary energy – DHW	kWh	835			0		
Absorption electrical energy	kWh				461		
System electrical energy consumption (circ. pumps)	kWh	293			90		
Specific electrical energy price	eur/kWh			0.09			
Total energy price	Eur	156	79	22	18	16	12
Heat source device/system price	eur	6500			15000		
Primary energy consumption	kWh	5720	2896	2638	2499	2400	2261
Annual CO_2 emissions	kg/year	570	289	263	249	239	225
Annual average solar fraction – SF	%		46	59	66	71	78

Conventional chiller cooling – average EER 3 – 600 kWh/year; Solar thermal system – Area/Storage tank volume = 1000 litres

CONSLUSION

In this paper were assessed the thermal performance of solar assisted air-conditioning system for residential buildings for weather conditions in Macedonia. Within the analysis are covered several solar thermal systems varying the collector area, hot water storage tank and the auxiliary heat source.

The simulation result reveals that in the heating season with the considered solar collector systems for building with heat energy consumption of 70 (kWh/m^2)/a, solar energy can cover from 19% to 44% of the required heating energy while for building with heat energy consumption of 57 (kWh/m^2)/a the solar energy can be covered from 22% to 55%. Also specific indicators are derived such as: with 0.1 m^2 flat plate installed collector area per m^2 conditioned area, with solar energy can be covered round 19–22% of the required heating energy and up to 55% coverage with 0.4 m^2 collector area.

For the cooling season are analyzed solar thermal systems with vacuum tube solar collectors and absorption cooling machine. Results reveals that, with 0.01 m^2 vacuum tube collector per m^2 conditioned area solar energy can cover 46% of the absorption chiller required heat energy, up to 78% coverage with 0.15 m^2 vacuum tube collector. Still solar thermal cooling has difficulty to emerge as a economically competitive solution mostly of still significally high investment costs.

Nevertheless solar energy provides high potential for reduction in greenhouses gases and primary energy which in Macedonia mainly is represented by fossil fuels, i.e. lignite coal.

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Original scientific paper

MODELLING THE SUCCESS OF SMALL AND MEDIUM ENTERPRISES

Bojan R. Jovanovski[1], Dragan Šutevski[2], Radmil Polenakovik[1], Valentina Gečevska[1], Ivana Stankovska[3]

[1]*"Ss. Cyril and Methodius" University in Skopje, Faculty of Mechanical Engineering, Karpoš II bb, P.O. box 464, 1001 Skopje, Republic of Macedonia*
[2]*Šutevski Consulting, Ilindenska 19, 1300 Kumanovo, Republic of Macedonia*
[3]*National Centre for Development of Innovation and Entrepreneurial Learning, Dame Gruev 1/2-17, 1000 Skopje, Republic of Macedonia*
bojan.r.jovanovski@mf.edu.mk

A b s t r a c t: The SMEs are the backbone of the economy, serving as catalyst for innovation and creativity, and buffer for the supply and demand of the corporations. All countries rely on the SMEs growth as a way for enhancing their resilience to face the new changes in the global economy. Despite the importance of high-growth SMEs, there is still lack of evidence regarding the factors and determinants for success. This paper aims to close this gap by reviewing the state-of-the-art and offering comprehensive overview of the success factors. A methodology for developing success model is outlined and initial model of success factors is proposed, supported by recommendations for future research. The presented results are valuable for the business owners and managers in the strategy planning, the policymakers and business support organizations in the designing of instruments, as well as for the universities in developing future educational and programmes for cooperation with industry.

Key words: competitiveness; success factors; high growth companies; SMEs

МОДЕЛИРАЊЕ НА УСПЕШНОСТА НА МАЛИТЕ И СРЕДНИ ПРЕТПРИЈАТИЈА

А п с т р а к т: Малите и средните претпријатија (МСП) се ‘рбетот на економијата, служејќи како катализатор на иновативноста и креативноста, но и балансер на побарувачката и понудата на големите компании. Државите се потпираат на растежот на МСП како алатка за зголемување на нивната флексибилност при соочување со новите промени во глобалната економија. Покрај важноста на брзорастечките МСП, сѐ уште се соочуваме со недостиг на познавање на факторите за успех. Овој труд е насочен кон зголемување на знаењето за оваа проблематика преку преглед на факторите за успех претставени во научната литература. Во трудот е претставена и методологија за развој на модел на успешност, претставен е и прелиминарен модел на фактори за успешност, како и препораки за идни истражувања. Презентираните резултати се важни за сопствениците на бизнисите и менаџерите во планирањето на бизнис-стратегијата, за креаторите на политики и организациите за поддршка на бизнисите за развој на инструменти за поддршка, како и за универзитетите за развој на идни наставни програми и програми за соработка со индустријата.:

Клучни зборови: конкурентност, фактори за успешност, компании со висок растеж, МСП

INTRODUCTION

Governments and policy makers for very long time have been focused on achieving economic growth, but only in the last period they have started to understand the importance of the successful and high-growth enterprises for achieving of that goal. On the other hand, although the businesses' primary goal is to make profit and sustainably increasing it, they have never had tougher challenge in competing in the global market. Due to this strong competition, customers' demands and the level of their complexity have risen not only in terms of the characteristics of the products and the service they require, but also the branding that is coming with it, the support provided, the ease of supply, the openness for future developments, etc. Although the understanding of these factors would be in a great importance for various stakeholders groups as it was presented, the actual knowledge for high-growth firms is very low and regarding their determinants it is even lower.

In the attempts of lowering this knowledge gap, the initial research problem is to select the companies in the targeted population. In the literature these companies may be defined as: successful, high-growth, high-performing, competitive and the whole research question is connected to innovativeness and even entrepreneurship and entrepreneurial behaviour. The success is usually analyzed as an internal dimension, defined with the company's mission, vision and goals, and measured by the percentage of their achievement. High-growth is usually considered mainly in terms of revenue growth, than number of employees, profit, and even export. But there is no consensus on the exact boundaries that need to be crossed for entering the group of high-growth companies. Even more there is no consensus on the importance of all growth measures parameters.

This paper is presenting the literature review of the-state-of-the-art regarding factors/determinants that are influencing the success, high-growth and/or competitiveness of small and medium enterprises (SME). All respective literature that was available for this research has been reviewed and more than 30 useful sources have been selected and further analyzed. In order to prepare a comprehensive overview including financial (such as investments in: R&D, marketing, human resources development, environmental protection, etc.) and non-financial factors (such as: strategies, human capital, tangible and intangible assets, etc.).

STATE OF THE ART ANALYSIS

General factors

Ownership of the company is connected to the performance, especially because different ownership options influence the fundraising possibilities and the competences from different owners. The type of ownership will also have direct impact of the managerial team's decision making and in such a way to directly design company's strategy. There are many researchers that try to connect the ownership with the performance of the companies and their success. Benjamin Balsmeier and Dirk Czarnitzki [1] in their research did not find significant linear relation between ownership concentration and company's performances, but discovered existence of the relationship for non-EU member states.

Location of the company also can have impact on the success of the companies. This is one of the more complex determinants as it has different influence as microlocation with much higher importance for some industries than others. On the macrolocation, Audretsch and Dohse [2] mentioned that location of the company is an „neglected determinant" when it comes to the research of success factors, and confirmed that location of a company is an important factor related to its growth performance especially having in mind availability of human capital, proximity to non-traded inputs and specialized goods as well as easy access to market. Michael Porter [3] talks about different industry activities in specific geographic regions that will have possible impacts on the companies' performances. Larger competition in a specific location will require companies to innovate if they want to be competitive. According to Porter, companies that operate in locations with industry clustering will require to be more innovative than companies that are located and operate from regions with lower level of industry clustering.

Although Gibrat's Law [4] states that the **size** of the company and its growth rate are independent, there are other researches that show contrary evidence. Although it is not strongly evident from the theory, it is logical to expect that larger companies would have larger potential in innovation. This statement is due to their physical infrastructure, variety of human capital – especially in the multinational corporations, as well as the expected relatively low influence of the failed projects over the financial stability. Having in mind research of Clayton M. Christensen [5], the success of innovation, especially disruptive innovation is not related to the size of the company. On the other hand, if we include the growth rate as a success performance indicator, it is logical that smaller companies will have larger growth rate than larger company who already passed high growth rate in their business life cycle. Barkham, Gudgin, Hart and Hanvey [6] showed from the research of SMEs with 50 persons or fewer that small companies grow faster than large. Also, Harhoff and Stahl [7] in their research of 11000 companies from manufacturing, construction, trade, finance, and services sectors find that likelihood of company's survival is positively related to the size, the growth is negatively related to the size and the likelihood of survival and growth rates are systematically different related to the different sectors of economic activities. Other researches also support nonexistence of Gibrat's Law when it comes to the company size. Doms, Dunne and Roberts [8] from their research in the US manufacturing sector show that older and larger sized companies have higher survival rates and lower growth rates. The differences in past researches do not provide conclusion regarding the Gibrat's Law, so it needs to be included in the initial model in order to be confirmed and dismissed in the further research.

With the **age** of the company there is huge accumulation of knowledge, experience and skills that can be used in order to expand the growth. Most studies on firm survival find that age matters. Dunne, Roberts and Samuelson [9] have conducted research on a census data from manufacturing and have discovered positive relation between companies' age and survival. Also, studies mentioned in the previous factor-size, all mention age of the company in the relation of growth, or that increase in the age of the company brings larger survival rate, but also lower growth rate for the company.

Financial determinants

The **financial data** have been used for two different purposes. The first purpose is to use income and profitability as success determinants that will show the success of the companies (income, profitability and investments). The second purpose of these data is to use them as factors that can have impact of the success of the companies. In addition to determents, we have used access to finance, return on assets, profit margin, profit per employee and cumulative profit, lose and investments in new equipment and processes.

Revenue streams are one of the business model elements described below in the section of business model as a success determinant for the companies. Revenue streams, the number of revenue streams and their efficiency in generating income for the company is the key success determinant as it is directly generating cash. One of the key decisions that company needs to make is to choose the right revenue streams that will enable future growth of income, profitability and also employability. Osterwalder and Pigneur [10] propose several ways to generate revenue streams: asset sale where company sell ownership rights to a physical product, usage fee, subscription fees, lending/renting/leasing, licensing, brokerage fees and advertising fees. Also, direct impact on the generated income will have two different types of revenue streams: transactional revenue from one time customers' payments and recurring revenue based on ongoing payments until the customer stops using the products and services from the company. Additionally, income and profitability will depend on the pricing strategies. Some of the most common pricing strategies are: fixed prices, prices dependable on different criteria, such as: quality or number of features, purchased quantity, characteristics of a customer segments, negotiations, inventory and time of purchase, supply and demand, and prices that are outcome of competitive bidding.

Access to finance in large part means availability of additional financial resources for the companies especially in order to support their growth. Wiklund, Patzelt and Shepherd [11] rank financial resources as one of the most important resources for small business growth. Dollinger [12] has stated that financial resources are valuable and necessary, but because financial resources are not rare, hard to duplicate, or non-substitutable, they are insufficient (in most cases) to be a source of sustainable competitive advantage. According to him, they are important because they can be converted relatively easy into other resources required for the success of the company.

Innovativeness

Innovativeness, or capability to innovate become one of the crucial determinants for the success of today companies. Considering the importance of innovation for the growth of the companies and the macroeconomic development, the research and scientific papers in the last few decades are focused on the measuring of the innovative potential including innovation enablers and innovation outputs. This is leaving a significant gap in the theoretical evidence of the actual influence of the innovation of the success of the company and its connection to the other elements. As Joseph Schumpeter said in his book "Capitalism, Socialism and Democracy", that "the fundamental impulse that sets and keeps the capitalist engine in motion comes from the new consumer goods, the new methods of production or transportation, the new markets, the new forms of industrial organization that capitalist enterprise creates" [13]. Today, the discussion of innovativeness, means not only to innovate new products and services, it is much more of that. Having innovative products or services will not ensure the success for the companies, if they could not be produced on a more efficient way, be delivered on the right way. According to Bruce and Birchall [14] over the last 15 years, three major trends have emerged: maintaining competitiveness has become a relentless drive toward improved efficiency and effectiveness, companies face increasing expectations from their customers and consumers and globalization no matter how big or small companies are, they are now competing on a global market. So, they conclude that if companies cannot compete on the basis of price (and today are there some who can? – authors comment) they will need to differentiate – and to differentiate, they will need to innovate. According to Davila, Epstein and Shelton [15] innovation occurs when companies change any of the major pieces of the technologies and the business model of the products and services they are delivering to their customers. So, they propose two levers of innovation: technology lever (products/services, process technologies and supporting technologies) and business model lever (value proposition, value network, target customers). Because business model is more complex, and process technologies and supporting technologies can be seen as processes in a company, it is evident that the focus of innovation will be on three elements: products and/or services, business model and processes. Nelson and Winter [16] relate innovation as an important source of entrepreneurial economic growth especially because it is fostered by the new products, technologies, processes, markets, methods, supply sources, and types of organizational arrangements. According to Pouder and St John [17], the performance of innovations can be measured according to the resources that company has allocated to research and development or the outputs as the number of patents issued. The conducted research has identified many variables related to innovativeness as type of technology that is used from the company, development of new technology in the industry in which companies exist, development of new innovative products and/or services and processes, the speed of innovation, improvements of existing products and/or services and processes, investments in research and development and registration of patents, trademarks, and industrial design, showing that this part of the model will have to be constructed very carefully.

Market and marketing

The type of the market on which a company sells their products and services and the way how they market them in large part will have impact on the success. The internationalization and globalization of companies is becoming part of the strategy of most companies all over the world in almost all sectors of operation, but for companies coming from small countries have strong influence on the ensuring growth and in some cases even survival. Thus, the companies that offer their products and services on foreign market is expected to have larger possibilities for growth. There are many studies and research evidences that relate internationalization of the companies with the performances (Rugman [18], Tallman and Li [19], Daniels and Bracker [20], Grant [21]).

Collaboration with Foreign Direct Investments (FDI) is important area that will need to be improved in the future. Internationalization is a broader term then exporting covering also partnership with foreign companies for building stronger competencies, outsourcing for increasing productivity and cutting costs, as well as attracting FDI. Although many studies connect FDI manly with large companies, even if SMEs do not have the potential in form of resources and capabilities to make direct investments in other countries (Johanson and Vahlne [22]), they are not limited to export their goods and services on a foreign markets, or to develop strong collaboration with the FDIs in their own country in order to expand their current geographical region.

Collaboration with public sector is not something that guarantee success for the SMEs. It is natural to relate collaboration with public sector with the success of the companies in countries where the government is one of the biggest customers and employers.

Internet marketing is still not utilized in full capacity in order to enable high growth, but it is becoming a very important tool for optimizing marketing costs and efforts, as well as a tool for achieving competitiveness on wider regional or the global market.

Business model as a success determinant for companies

There is no consensus on a specific definition of business model. The proposed definitions focus on different components and structures of the business model. There is also a problem in unifying the terminology. Terms such as business model, business concept, business strategy, revenue model etc., are often used with the same mining. The business model has been referred to as architecture, design, pattern, plan, method, assumption, and statement [23].

In the analysis of the literature for business models, we need to relate it closely with a term that is relatively new, but describe the relationship with the growth and success of companies. It is scalability that has large expanding in discussions when it comes to the literature related to the growth of the companies. According to Bondi [24] the scalability is desirable attribute of a network, system, or process that presents the ability of a system to accommodate an increasing number of elements or objects, to process growing volumes of work gracefully, and/or to be susceptible to enlargement. Therefore, scalability will show the preparedness of a company to grow, to ensure that the business model will support the growth of the company. On the other side, according Blank & Dorf [25] scalable start-ups are the work of traditional technology entrepreneurs with a believe that their vision will change the world. They also talk about buyable start-ups as a totally new phenomenon where instead of scalability these companies tend to "buyability". As a low cost companies they want to come to the degree where can be acquired by larger companies often to acquire the talent. These companies do not need to be scalable, they need to show their talent to produce the values. Chesbrough & Rosenbloom [26] through analysis of many definitions related to business model offered a definition related to functions of the business model: articulation of value proposition, identification of a market segment, definition of the structure of the value chain, estimate cost structure and profit potential, description of the company's position within the value network and formulation of the competitive strategy.

Morris, Schindehutte and Allen in their paper have provided a review of existing perspectives and propose of the business model. According to their research, the number of components mentioned varies from four to eight. A total of 24 different items are mentioned as possible components, with 15 receiving multiple mentions. The most frequently cited are the firm's value offering (11), economic model (10), customer interface/relationship (8), partner network/roles (7), internal infrastructure/connected activities (6), and target markets (5). Some items overlap, such as customer relationships and the firm's partner network or the firm's revenue sources, products, and value offering [23].

Osterwalder and Pigneur, the authors of the business model canvas [10] define business model as a rationale of how organization creates, delivers and captures the value. Their model is consisted of nine elements that are similar to the functions defined by Chebrough and Rosenbloom: value propositions, customer segments, channels, customer relationships, revenue streams, key resources, key activities, key partnerships and costs structures. According to Teece [27], good business models achieve advantageous cost structures and generate value propositions acceptable to customers. So, it is obvious that the growth of the companies has an important relation to the ability of the companies to design and redesign effective business models. Conducting really extensive literature review related to business models and the success of the companies, it is evident that the business model is fundamental to the success of the company and especially in creating the ability of the company to commercialize important innovations.

The first and one of the most important elements of the Business Model Canvas is value proposition presented as a reason why customers choose one company over the other. So, better, stronger, more useful for customers value proposition will help companies to ensure success and high growth, because it is the only thing that will be in the customers hands ready for valuation for the future relationship with the specific company. All other elements of the business model will exist to improve overall customers' satisfaction and ensure that the value as it is designed and produced will become available for the customers. The same authors propose a non-exhaustive list of elements that can contribute in the creation of the value to the customers: newness, performance, customization, design, brand, price, cost reduction, risk reduction, etc. Because all of these elements can have large influence on the customers' buying decision, having the right mix of these elements the larger likelihood will be for the success of the companies, especially in their growth in revenue, profitability and employability. Kim & Mauborgne [28] talk about creating blue oceans in which companies will drive costs down while simultaneously drive value up for the buyers. They describe this value as a value innovation created in the region where a company's actions favourably affect both its cost structure and it is value proposition to the buyers. According them, cost savings are made by eliminating and reducing the factors an industry competes on and buyer value is lifted by rising and creating elements that industry has never offered.

There could not be something worse than the attempt to sell products and services to the wrong customers, or to someone who less likely to want or to need the offered products and services. The customers are the heart of any business model canvas and without profitable customers the company would not survive for long. There can be different types of customers segments as: mass market (customers with broadly similar needs and problems), niche market (targeting specific requirements of a niche market), segmented market (more segments with similar needs and problems), diversified market (more segments with totally different needs and problems), and multi-sided market (more independent customer segments where one of them will bring income to the company only because of the existences of other segments).

The goals of different customer relationship as a part of business model is to acquire new customers, increase the retention of current customers or simply increasing income through some types of up-selling. In the Business Model Canvas several categories of customer relationships are distinguished, such as: transactional, long-term relationship, personal assistance, dedicated personal assistance, self-service, automated services, communities and co-creation.

Channels as a part of a company's business model will define how company communicate and reaches its customers segments in order to deliver the value proposition to them. When we talk about the growth of a company, channels can play important role especially about effectiveness in reaching larger customers' base, effectiveness of the specific channel and cost-efficiencies of the specific channel that is used from the company. Osterwalder and Pigneur [10] say that "an organization can choose between reaching its customers through its own channels, through partner channels or through a mix of both".

When we look closely on the way how companies operate today, it is evident that they are not isolated "islands" and dependency on a strong network of suppliers and partners simply makes it possible for the business model to work as it is designed. Ron Adner [29] described this on the following way: "More and more, managers and executives are being pushed into a world of greater collaboration. The upside is that, by working in concert with others within and across organizations, you can accomplish greater things with greater efficiency than you could ever accomplish alone. The downside, however, is that your success now depends not just on your own efforts but on your collaborators' efforts as well. Greatness on your part is not enough. You are no longer autonomous innovator. You are now an actor within a broader innovation ecosystem. Success in a connected world requires that you manage your dependence." It is evident that in today's connected and collaborated economy partnership with other domestic and foreign companies as well as other institutions is important to ensure that the right value gets in the hands of the right customers. Osterwalder and Pigneur [10] also talk about three motivations for creating partnerships: optimization and economy of scale, reduction of risk and uncertainty and acquisition of particular resources and activities that are also next elements of the business model.

This element of the business model describes the most important activities that a company must do in order for the business model to operate in the way as it is designed. Key activities can be categorized as [10]: production as designing, making and delivering products, then services or activities based on problem solving that will require knowledge management and continuous training and as a last category is maintaining platform or network as a product for company.

Everything based on paper as a business model, or business plan could not be considered as accurate or reliable without the necessary resources in a form of important assets of the company. With these resources the companies can be able to create and deliver the value proposition, communicate with customers, and earn revenue to maintain high level of profitability and growth. In the Business Model Canvas the key resources are classified as: physical, intellectual, human and financial resources. All these factors are important in reaching success.

Costs are unavoidable counterpart of the businesses; they are in fact necessary for fulfilling the operative business activities. On the other hand, costs have direct impact on the profitability of the company and possibilities to grow. Type of the cost structure that the business model will require is important determinant in reaching success. Osterwalder and Pigneur [10] say that even there are two broad classes of business models' cost structures (cost-driven and value-driven), still many business models will fall in between these two extremes. So, they identify following cost structures: cost-driven, value-driven, fixed costs, variable costs, economies of scale and economies of scope.

Human resource management to increase organization's human capital

Human capital is important for the growth of the company because it consists the knowledge, skills and experience of the organization. Greater potential of human capital, the greater growth of the company will be possible. According to Chandler and Hanks [30], human resources in an organization with larger human capital can enable growth of the organization, enabling management and owners to implement their growth goals. Also, Wiklund, Patzelt and Shepherd [31] put the human capital as one of the most important resources for small business growth in addition to financial resources. It is evident that human capital of an organization is important for the growth. Jan de Kok [32] has shown in his research that smaller firms, such as family-owned and managed organizations are, ceteris paribus, less likely to have an HRM department.

CONCLUSION

Based to the extensive state-of-the-art analysis, it has been observed that many authors have been engaged in the analysis of the success factors and its level of influence over the company's success. Also, there are some indications on how to measure success of a company from external point of view. Nevertheless, for both issues there is not any commonly agreed model of success influencing factors, or success measurement system, but rather different opinions and empirical evidence. This may occur as a significant problem in the attempts to create overview of the specifics of a sector, or a region, but it is rather challenging for researchers for creation of a general model or methodology for determination of this kind of model and / or measurement system.

On Figure 1 the initial model of success factors has been presented. Although this model contains most of the identified factors by the literature, it lacks region/sector based inputs and interdependence links between different factors.

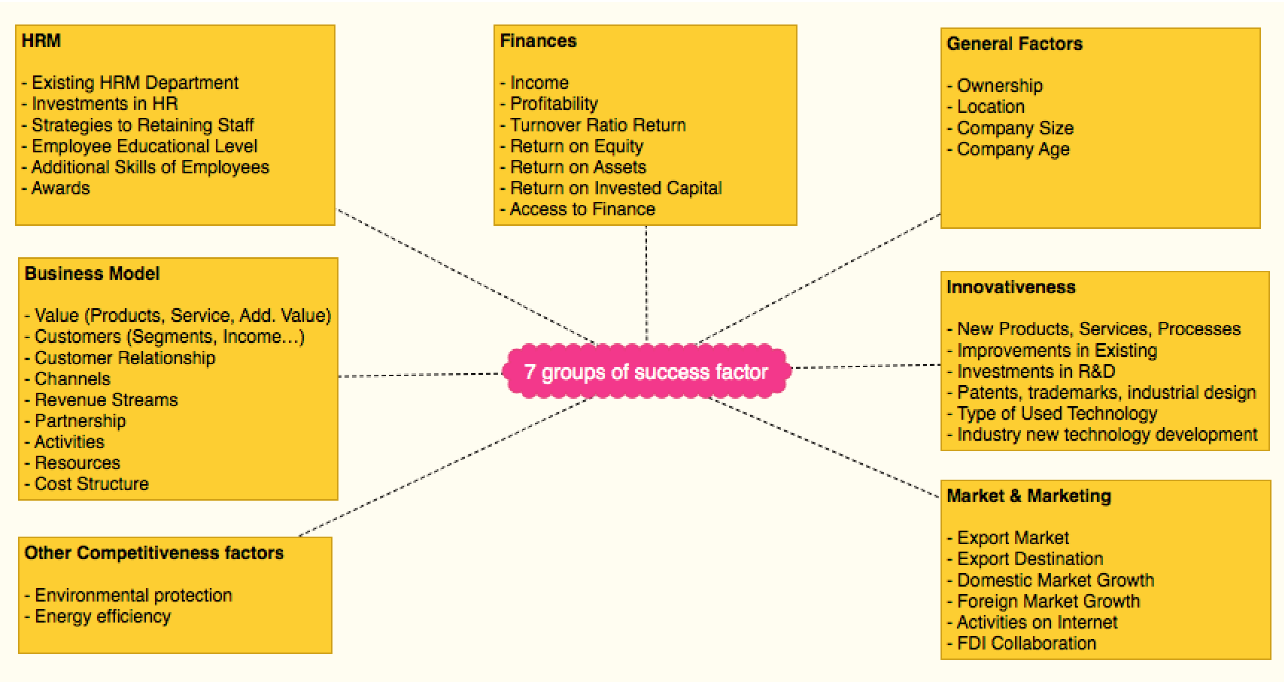

Fig. 1. Initial model of SMEs' success factors

RECOMMENDATIONS FOR FUTURE RESEARCH

In order to have precise overview of the success influencing factors in a region or sector of operation, this analysis needs to be enlarged with inputs from mangers of successful companies from the targeted population. These inputs should be sufficient for creation of the initial model including interdependences. This model needs to be analyzed, modified and then validated by a group of experts from academia, governmental and non-governmental business support organizations, as well as managers of successful companies. The group of experts should also provide importance of the tangible outputs, which would be used to determine the success rate of the analyzed companies. The modified model, enriched with the importance of the respective interdependences, needs to be checked through:

1. Survey – questionnaire conducted to a sample of at least 100 companies.
2. Interviews with 5–10 successful companies.
3. If possible for more reliable results, to be verified thought statistical analysis of the available data of the whole population.

Based on the survey, interviews and statistical analysis, if required the model will be fine-tuned and the final version of the model should be verified through in-depth analysis of a company or using a simulation software.

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