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UNION OF ENGINEERS AND TECHNICIANS OF SERBIA

BACKGROUND

The roots of Serbian technical civilization date as early as the time of the Nemanjics. Beginnings of engineering activities were associated to the mining and metallurgical undertakings (Novo Brdo) and to building of magnificent medieval sacral structures of the Serbian state.

After the First (1804) and second Serbian Uprising (1815) the technical tradition was renewed and Serbian joined the then current European trends. First educated engineers came in Serbia from Austro-Hungarian Empire in 1830s. At that time, the main preoccupations of engineers were railway construction, town planning, construction of sewage disposal and water supply systems, as well as creating of national defense system. At that time 1834/35 from Austrian Empire arrived first schooled engineers France Janke and Franz Baron Kordon who served as so called “drzavni indzilirin” or state engineers.

In Serbia in the 19th century there were a total number of about 6000 engineers engaged in various activities. In an eighty-year period from 1834-1914 the State Construction Administration (which from 1880 also included railways) employed one third of these engineers. However other ministries were also competent for some engineering affaires like, for example the Ministry of Finance was responsible for mining, or the Ministry of Education and Church Affairs was responsible for education of technical stuff. From 1838 this primarily referred to the Licej: according to “Establishment of public institutions of learning” of 1844, the Department for Philosophy included also subjects such as Pure and Practical Geometry and Higher Mathematics, and Architecture, while in 1853 a separate Natural Sciences and Technical Department was introduced in the Licej and in 1863 the Great School with Technical Faculty started operating. The first classes held at the Technical Faculty

of the Great School in 1863 marked turning point in schooling of Serbian engineers.

Out of some 600 engineers, approximately one third were schooled in Serbia and one fifth of them studied abroad as “state grants students”, while about one fourth were foreigners and Serbs from “across the Danube”.

In 1868 one of preconditions which might have contributed to professional associating of engineers was the numerosity of professionals and models from abroad established half a century earlier (engineering associations in Great Britain, Germany and America) had influence on establishing professional associations in Serbia.

The Founding Assembly of the Technicians’ Society was held on the 3rd February 1868 in the premises of Great School. Engineer Emilijan Josimovic was elected for the first President of the Society. It is important to mention that this happened only a year after Turkish commander in Belgrade Ali -Riza pasha gave the town and the fortress keys to duke Mihailo Obrenovic. Shortly afterward in 1869 was established Society for Agrarian Economy that is the Serbian Agricultural Society. Association of Serbian Engineers was established in 1890 while in 1896 was established the Association of Serbian Engineers and Architects.

The first scientific magazine published by this Association in 1890 was “Srpski tehnicki list” The “Srpski tehnicki list” besides professional articles also published detailed information related to the work of the Association. The members at that time, who numbered around one hundred of them, initiated a whole series of issues and demand the same to be solved by the competent bodies. During the First World War, two volumes of “Srpski tehnicki list” were published in Thessaloniki. The magazine was initiated by the engineers and architects who were in Thessaloniki as members of the Serbian Army. In Thessaloniki was

held the General Assembly of the Association in 1918 attended by 463 engineers.

During his short stay in Belgrade, in 1892, famous scientist Nikola Tesla was elected for the first honorary member of the Association of Serbian Engineers.

Providing assets from its own incomes, bank loans, gifts and donations of its organizations-members and its individual members Association built the House of Engineers in Belgrade, Kneza Milosa 7 str in 1932/35. The House of Engineers "Nikola Tesla" in Belgrade Kneza Milosa 9-11 str was built between 1962 and 1969. In the premises of these two Houses of Engineers besides the Union of Engineers and Technicians of Serbia today perform their activities 26 republic's professional and multidisciplinary engineering-technicians' associations out of 41 collective members of UETS.

Besides **Emilijan Josimovic** who was first President of the Technicians' Society, prominent figure of that time, Rector of Licej and Great School and honorary member of the Serbian Royal Academy, to work of our Union contributed as well: **Kosta Alkovic**, professor at the Great School, Minister of Construction and member of Serbian Learned Society and Serbian Royal Academy, **Dimitrije Stojanovic** professor at the Technical Faculty, first Director of Serbian State Railways, and member of Serbian Learned Society and Serbian Royal Academy, **Milos Savcic**, Minister of Construction and President of Belgrade Municipality, famous businessman who gave the greatest donation for the construction of House of Engineers in 1932, as well as presidents of the Serbian Academy of Sciences and Arts **Josif Pancic**, **Jovan Zujovic**, **Simo Lozanic**, **Kirilo Savic**, **Aleksandar Despic**, **Nikola Hajdin** and other famous scientists.

ACTIVITIES

The Union of Engineers and Technicians of Serbia - Savez inženjera i tehnicara Srbije is a voluntary, non-governmental, non-profit, scientific, interest, professional, non-party organization of engineers and technicians, and their organizations in the Republic of Serbia, open for cooperation with other scientific, commercial and other organizations, on the basis of mutual recognition, mutual respect and independence in work.

Union of Engineers and Technicians of Serbia and its collective member finance their own activities from their own assets.

Purposes and tasks of UETS are:

- Assembling and organizing of engineers and technicians of Serbia for the purpose of increase of

their expert knowledge, providing appropriate status in the community, on the basis of their contribution to the, scientific-technological and economic and development in general of Republic of Serbia;

- Joining, strengthening and massification of basic engineering-technicians' organizations of Serbia, development of mutual cooperation as well as the cooperation with appropriate international organizations of engineers and technicians;
- Improvement of order-interest, reputation and protection of members of the engineering-technicians' organization of Serbia;
- Providing help to engineers and technicians in scientific, expert improvement and organization of appropriate forms of permanent education;
- Monitoring contemporary development of engineering and technology and pointing out the currents of events and changes in this area and providing opinions on optimality of engineering and technological solutions in investment and other enterprises;
- Caring for and development of ethics of engineering-technician profession, human rights and liberties;
- Stimulating, organization and publishing of scientific and expert papers, magazines and other publications of interest for engineering-technician organization and technical intelligence;
- Work on technical regulations (laws, regulations and standards), providing its modernity, adequacy, actuality and functionality;
- Consideration and providing expert opinions on plans, programs, analysis and other acts, which are important for the development of engineering, technology and production in the Republic of Serbia;
- Stimulating and helping the activities and initiatives, aiming to preserve the human environment and area organization, saving and rationalization of spending of all sorts of energy;
- Preparation and maintenance of the meetings with purpose of permanent education of engineers and technicians;
- Providing help in development of technology and economy whose purposes are similar to the purposes of engineering-technicians' organization;
- Organization of multidisciplinary meetings and meetings of wider social importance;
- Cooperation with appropriate expert, commercial organizations and other organizations and organs at the realization of tasks of mutual interest;

- Management of Houses of Engineers and other property of Union of Engineers and Technicians of Serbia.

Union of Engineers and Technicians of Serbia has developed cooperation with organs of local government, state ministries, Serbian Academy of Sciences and Arts, Serbian Chamber of Engineers, Engineering Academy of Serbia, Chamber of Commerce and Industry of Serbia, with numerous companies, professional associations, faculties and universities and other institutions. UETS also has developed international cooperation.

In accordance with the Law and Contract with republic ministries in the framework of UETS are organized and performed specialist exams for several engineering branches.

Union of Engineers and Technicians of Serbia has several thousand individual members and 41 collective members in the Republic of Serbia: 19 republic's professional associations (associations of architects, town planners, mechanical engineers, electrical engineers, mining and geological engineers, surveyors, agricultural engineers, chemical engineers etc) 7 republic's multidisciplinary engineering-technicians' associations (ecology, standardization and quality, material protection and corrosion, informatics etc) 1 provincial engineering-technicians' association, 14 municipal and regional engineering-technicians' associations.

Union of Engineers and Technicians of Serbia is founder of the Engineering Academy of Serbia, and collective member of the Chamber of Commerce and Industry of Serbia.

Union of Engineers and Technicians of Serbia, in a cooperation with faculties, universities, enterprises, economic and professional associations organizes various scientific meetings, professional reunions, congresses, seminars, conferences. UETS members

publish their expert magazines; "KGH"; "Procesna tehnika", "Ecologica", "Tekstilna industrija", "Forum", "Sumarska industrija", "Zastita materijala" and maintain professional reunions, seminars, conferences and congresses in branches of architecture, mechanical engineering, chemistry, electrical engineering, agriculture, forestry etc.

All activities of the Union are performed in accordance with the procedures and standards of **QMS - Quality Management System**.

Union of Engineers and Technicians of Serbia is National member of **FEANI – European Federation of National Engineering Associations** from Serbia. FEANI is a federation of professional engineers that unites national engineering associations from 32 European countries. Thus, FEANI represents the interests of over 3,5 million professional engineers in Europe. FEANI is striving for a single voice for the engineering profession in Europe and wants to affirm and develop the professional identity of engineers. Through its activities and services, especially with the attribution of the EUR ING professional title, FEANI aims to facilitate the mutual recognition of engineering qualifications in Europe and to strengthen the position, role and responsibility of engineers in society.

Union of Engineers and Technicians of Serbia is member of COPISE – Permanent Conference of the Engineers of Southeast Europe.

Collective members of UETS are members of international professional associations and have developed international cooperation.

With all that has been done and with accomplished results, objectively solid conditions have been provided for further and more successful work, business operation and development of the Union of Engineers and Technicians of Serbia.

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TECHNICS

NEW MATERIALS

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Hydrogen Storage-Challenges of Today

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Review paper

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The main reason for the growing interest in hydrogen economy is the fact that hydrogen economy may be a solution to the two main challenges facing the world now: the climate change and the need for secure supply of energy. To make transition from present carbon based economy to hydrogen economy several problems has to be solved, regarding production, safety and storage. From all possible solutions for hydrogen storage (gas cylinders, liquid tank, solid state storage), the one which relies upon storage in solid media, such as hydride is the most attractive one. Solid-state storage implies hydrides such as metal/intermetallic and complex- chemical hydrides. Since the release of hydrogen from hydrides takes place via an endothermic process, this method of storage is the safest of all mention, but the problem of slow sorption process and high temperature of desorption has to be solved if hydrogen will be used as an energy carrier. In the past two decades many studies were performed, either experimental or theoretical with the same subject - how to overcome these drawbacks. Sluggish thermodynamics and slow sorption/desorption kinetics can be altered by MgH_2 destabilization – throughout surface modification and structural deformation. To improve the diffusivity of hydrogen in the metal hydride, various techniques such as ball milling and ion bombardment are applied, which in turn reduces the particle size, increases the defect concentration and shortens the diffusion paths for hydrogen. Also, sufficiently fast hydrogen sorption kinetics has been achieved by using metals, metal oxides, transition metal and transition metals oxides as additives in process of milling. In this short review we have try to summarize some of the results of above mentioned methods of destabilization.

Key words: hydrogen economy, hydrogen storage, metal hydrides, destabilization of structure, thermodynamic and kinetic properties

1. INTRODUCTION

1.1 Hydrogen and hydrogen economy

Recent research in terms of replacement of fossil fuels with alternative energy sources goes in favour of

widespread use of hydrogen as an energy source. It is therefore expected that the transition to a hydrogen economy can solve problems caused by use of fossil fuels. Some of the advantages of using hydrogen can be easily seen from the combustion reaction:



One of advantages is the elimination of pollution caused by fossil fuels, because hydrogen combustion in fuel cell produces only water. Furthermore, there is no emission of greenhouse gases if H_2 is produced by

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electrolysis of water or if the used electricity is obtained without using fossil fuels, i.e. from renewable sources e.g. from nuclear power, hydropower, solar cells or wind energy.

The great advantage is that hydrogen can be produced wherever there are electricity and water. However, there are technological problems that have not been resolved yet, so hydrogen could not be used widely as a fuel. The great challenge is to solve the problems of hydrogen storage primarily for applications in the automotive industry, because the hydrogen is gas in its ground state and occupies a large volume. Further, there is to find a balance between the requirements for high-capacity (need a strong chemical bond) and a large number of repeating cycles of hydrogen charging/discharging from the system in which it is stored (need a weak chemical bond).

Hydrogen is a gas, but may be stored in both liquid and solid state. In the case of storage in a solid state, hydrogen is stored in the form of chemical compounds, rather than as a pure compound.

None of the current methods of hydrogen storage is at the same time effective in terms of energy density, the volume or mass of the entire system and the rate of release of hydrogen. Compared to the fossil fuels, such as gasoline, hydrogen has the apparent lack of an amount of energy that can be stored in a given volume. Liquid hydrogen has about 2.6 times more energy per unit mass than gasoline, but four times bigger volume is needed for a given amount of energy [1]. The Department of Energy (DOE) has set a goal of onboard hydrogen storage for light-duty fuel cell vehicles. Target for 2017 is hydrogen storage capacity of 5.5 wt% H or 4.0 kg H/m³ system, or as an ultimate goal is 7.5 wt% H₂ or 7.0 kg H₂/kg system [2]. Some storage technologies can already meet these

requirements, such as magnesium, but they do not show other required characteristics, such as high enough speed of charge and discharge system with hydrogen at a suitable temperature and the reversibility of the process (Table 1).

Finding a suitable storage method is the biggest problem in order to hydrogen could be widely used for mobile applications, i.e. transportation. The problem of storage is less pronounced in stationary applications.

2. HYDROGEN STORAGE METHODS

2.1 Gas cylinders

Hydrogen, the smallest and the lightest known molecule, has a high ability to diffuse through solids in the gas phase and get away from the system even through the smallest opening in joints and seals.

Steel or aluminium tanks at a pressure of 200-250 bar are the most used method for commercial distribution of hydrogen. These tanks are heavy with relatively low energy density. Tanks with hydrogen under 200 bar pressure contains only 17 kg H₂/m³ [3]. Newer cylinders can stand pressures of 800 bar, providing a bulk density of 36 kg H₂/m³, which is two times lower than density of the liquid at the boiling point [4].

Gas pressure technology is preferred in the case of storage and distribution of hydrogen, because it is well built and has extensive infrastructure. Improvement of characteristics is made in the direction of creating the lighter cylinders. Required energy for compressing hydrogen from atmospheric pressure to 450 bar is 25 kJ/mol, which is relatively small amount comparing to liquefaction of hydrogen [5].

Table 1. Comparing different methods for hydrogen storage [3].

Method	Density of stored hydrogen		Disadvantages
	Mass (%)	Vol (kgH ₂ /m ³)	
Gaseous hydrogen under pressure	13	33	Safety problem due to high pressure
Liquid hydrogen	100	71	Safety problem due to low temperature
Solids with large surface area	2-5	20	Small volume density
Metal hydrides	2-7	150	Slow sorption reaction
Complex hydrides	18	150	Adsorption at high pressure; desorption at higher temperature
Metal oxidation with water	14	□ 100	not reversible

2.1.1 Underground storage of hydrogen gas

Large underground warehouse, similar to those used for natural gas storage is special case of storing gaseous hydrogen. In both cases, whether it is on the storage of hydrogen or natural gas, produced energy has the potential to meet the needs of large communities for a long time [5]. For example, in the valley of Tess in the UK, 1000 tons of hydrogen has been stored under populated area and is distributed by 30 km pipeline [6].

2.2 Liquid hydrogen

Liquid hydrogen requires cryogenic store in special thermally insulated containers. To remain liquid, hydrogen has to be kept under its critical temperature (33 K). Since this temperature requires pressure of 13 bars, in practice, liquid hydrogen is usually stored at atmospheric pressure and temperature of 20 K.

Advantage of storing hydrogen in liquid state is in energy per mass preservation and it is around 2.6 times higher than in gas state [7]. Volumetric density of liquid hydrogen is 70.8 kg/m^3 . The real challenge is to keep hydrogen in liquid state with efficient energy use for liquefying process. On the other hand, thermal isolation of cryogenic tanks has to be satisfied in order to prevent hydrogen vaporisation [4]. Other disadvantages of hydrogen liquefaction process are in demands of keeping constant low temperature – below critical temperature, in high price of producing cryogen tanks and in unsafe handling of liquid hydrogen [7].

Hydrogen molecules exist in two forms. These two forms can be distinguished by direction of nuclear spins in both atoms in hydrogen molecule. In ortho-hydrogen, nuclear spins are oriented in same direction, while in para-hydrogen spins have reversed direction. Keep in mind that molecular weight of ortho- and para-hydrogen are the same, so they are not isotopes. At room temperatures, hydrogen exists in mixture of both forms: 25% of it is para- and 75% is ortho-hydrogen. Para-hydrogen is more stable than ortho forms at lower temperature, and all ortho-hydrogen molecules is converted to para-hydrogen at 20 K. This conversion is followed by releasing heat around 1 kJ/mol which is higher than heat of vaporisation (about 0.9 kJ/mol), meaning that during molecule transformation from ortho- to para-form, liquid hydrogen can be considered as ever-present source of heat. Because of this, it is very important to accomplish conversion, as much as it is possible, during process of liquefaction [8]. Usually, the sellers can guarantee that 98% of hydrogen in tank is in para-form. Density of liquid hydrogen has generally low value for liquids and is 70 kg/m^3 (Figure 1). Due to

the fact that liquid hydrogen has high density and that it can be handled at atmospheric pressure, it has priority in numerous great industrial distribution networks. Disadvantage of liquefaction is that 30–40% of total hydrogen energy is used for the process. Heat of vaporization is about 1 kJ/mol, but in liquefaction installations, process of liquefying hydrogen at 20K requires 90 kJ/mol [9].

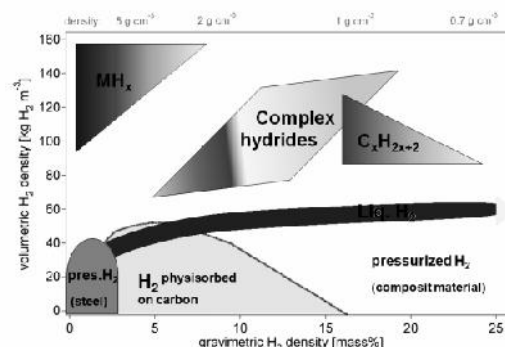


Figure 1 - Gravimetric and volumetric density of hydrogen storage materials.

2.3. Solid state hydrogen storage

Storing hydrogen in solid state form is the safest and the most effective way of hydrogen handling. By this, it is not refer to storing hydrogen in its elemental state, but to method based on hydrogen-solid substrate interactions (Figure 2).

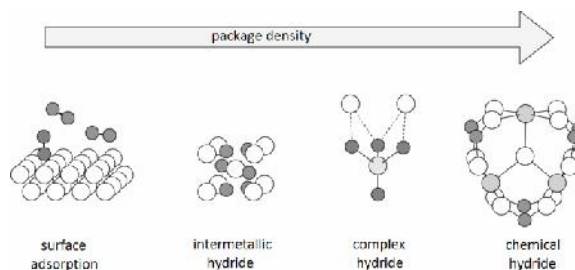


Figure 2. – Hydrogen storage methods

Stored in solid state, hydrogen has the largest volumetric density which depends on type of metal or hydride.

According to bonding type between hydrogen and material, solid state storing methods can be divided to:

- hydrogen adsorbed on material with great specific surface area (at $T < 1000 \text{ K}$),
- absorption in interstitial positions in the crystal lattice (at atmospheric pressure and room temperature)
- chemically bonded in covalent or ionic compounds such as ammonia NH_3 (15,1 wt% H) and methanol CH_3OH (8,9 wt% H at room temperature).

Other way to get hydrogen is to release it by oxidising reactive metals (i.e. Li, Mg, Na, Al, Zn) with water. Reaction is not directly reversible but it is possible to reduce produced hydroxide to metal in solar furnaces.

2.3.1 Hydrogen adsorption in solids with large surface area

Great advantages of hydrogen storage based on physisorption in materials with large specific area, are low pressure, relatively low price of materials and simplicity of design of storage system. Disadvantages that prevent wider application are low capacity of bonded hydrogen and necessity of low operation temperature. Carbon nanostructures and nano-porous materials (zeolites, metall-organic compounds) are structures that are recently investigated as possible materials for hydrogen storage [4, 10-12].

The amount of adsorbed hydrogen on surface of solid substrate depends on pressure, temperature and surface type. Adsorption mechanism includes van der Waals physisorption of hydrogen molecules and chemisorption of hydrogen atoms followed by dissociation of hydrogen molecule.

The maximum capacity of hydrogen absorption in different carbon based materials at 65 bar and 77 K is less than 4.5 wt%, and at 298 K is less than 0.5 wt% [13]. Tagaki et al. obtained similar results for activated carbon fibers and carbon nanotubes and showed that adsorption at 303 K and 3.1MPa is less than 0.3 wt% [14].

Currently, at 77 K and high pressure the maximum adsorption of hydrogen on porous carbon based materials is around 5%, and on porous metal-organic framework (MOF) materials around 7.5%. Carbon nanotubes are good material for hydrogen storage [15, 16], It was shown that physisorption is the mechanism for hydrogen storage in carbon nanotubes at 77 K and the room temperature and that maximum capacity of absorbed hydrogen depends on specific surface area (for specific surface of 1000 m²/g capacity is 1.5 wt%) [17].

2.3.2 Storage of hydrogen in form of metal hydrides

Metals, alloys and some intermetallic compounds can absorb large amount of hydrogen in both ways as molecule in gaseous phase and as atom from electrolyte. In the first case, hydrogen molecules dissociate at the surface before absorption, Figure 3. Many metals form hydrides by embedding hydrogen atom interstitially in crystal lattice. Structure of the lattice is mostly metallic with hydrogen atoms placed interstitially and because of that usually they are called interstitial hydrides. Interstitial hydrides may have general formula MH, MH₂ or MH₃, with hydrogen

atoms packing in octahedral or tetrahedral host of metal lattice [4].

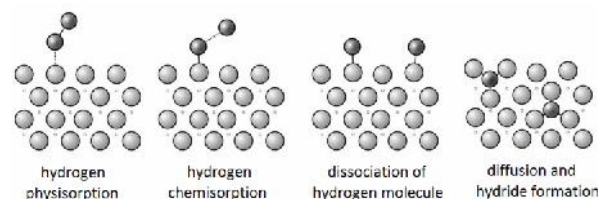


Figure 3 - Schematic representation of all reaction sorption stages

Special types of metal hydrides are hydrides of intermetallic compounds. The simplest example is ternary system AB_xH₂ where a variation of molecular ratio of elements changes properties of hydride. Element A is earth alkaline metal or rare earth element which tends to form stable hydride while element B is transition metal which forms unstable hydrides. Some of the intermetallic compounds that are of interest for hydrogen storage are summarized in Table 2 [4].

Table 2. AB₅, AB₂, AB, A₂B i bcc intermetallics and their properties for storing hydrogen [4].

Metal	Hydrid	mass %	p _{eq} (bar);T (K)
Pd	PdH _{0.6}	0,56	0,02; 298
LaNi ₅	LaNi ₅ H ₆	1,37	2; 298
ZrV ₂	ZrV ₂ H _{5.5}	3,01	10 ⁻⁸ ; 323
FeTi	FeTiH ₂	1,89	5; 303
Mg ₂ Ni	Mg ₂ NiH ₄	3,59	1; 555
TiV ₂	TiV ₂ H ₄	2,6	10; 313

The thermodynamics of hydride forming by absorbing gaseous hydrogen in metal can be described with isotherms $P=f(C_H)$, (Figure 4). The metal matrix dissolves hydrogen to form solid solution (α – phase). As hydrogen pressure growing, the concentration of dissolved hydrogen also increases, and nucleation process and growth of hydride phase (β -phase) occur. Transformation from metal to hydride β – phase is continuous at critical temperature T_c . In pure hydride phase, increasing of hydrogen pressure leads to increasing of absorbed hydrogen in hydride.

Throughout a coexistence of solid solution and hydride phase, isotherms demonstrate flat plateau. The plateau length determines the quantity of reversibly stored hydrogen i.e reversible stored hydrogen capacity. Van't Hoff equation describes relations between equilibrium pressure and temperature while enthalpy of formation can be found from the slope of the van't Hoff plot, $\ln p = f(\frac{1}{T})$. Van't Hoff

diagrams of some hydrides are presented in Fig 5; for equilibrium pressure of 1 bar at 300 K, ΔH is 19.6 kJ/mol of hydrogen. The operating temperature of metal hydrides is determined by plateau pressure in

thermodynamic equilibrium and by kinetics of total reaction [18-20].

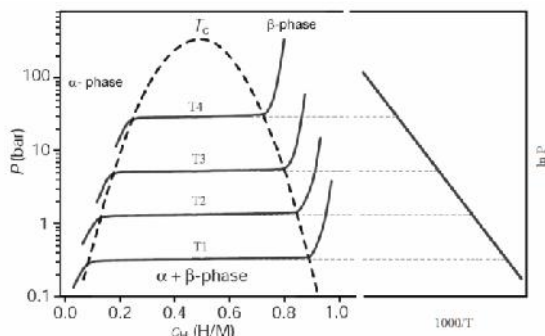


Figure 4 - Isotherm $P=f(C_H)$ for hydrogen absorption in metal (ideal behaviour), and Van't Hoff diagram (right)

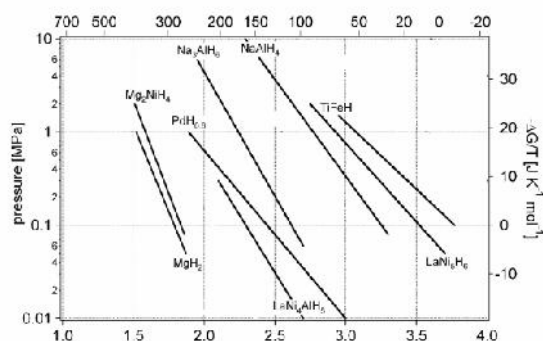


Figure 5 - Van't Hoff plots of selected hydrides

As it can be seen from the Figure 5, many metals form hydrides, including palladium ($\text{PdH}_{0.6}$), rare earth metals and magnesium hydride (MgH_2) which are not in pressure – temperature range suitable for mobile storage application: 1 - 10 bar and 0 - 373 K (corresponding to an enthalpy change in range 15 - 24 kJ/mol H_2) [5]. Some of complex and intermetallic compositions form hydrides which can absorb and desorb hydrogen at room temperature and pressure close to the atmospheric pressure, showed in Table 1 [4].

Complex hydrides are metal – hydride complex compositions of I, II and III group of elements of periodic table (e. g. Li, Mg, B, Al). These hydrides are interesting because of their light weight and presence of high number of hydrogen atoms per metal atom – usually 2.

For instance, hydrogen in complex hydride, which consists of B or Al in a centre, is placed in corners of a tetrahedron. Negatively charged anion $[\text{BH}_4]^-$ or $[\text{AlH}_4]^-$ is compensated by cation Li^+ or Na^+ . These types of systems very often have high decomposition temperature because of their specific chemical structure and unique nature and it is necessary to find compatible catalysts (Figure 2) [4].

3. MAGNESIUM HYDRIDE AS HYDROGEN STORAGE MATERIAL

Magnesium hydride (MgH_2) appears as attractive material for hydrogen storage since it has suitable properties like high gravimetric (7.6 wt%) and volumetric densities (130 kg H_2/m^3), light mass, abundance, low price and non-toxicity.

However, this hydride has not found wide industrial application since it's very stable (enthalpy of formation ($\Delta H = -75$ kJ/mol H_2)). High desorption temperature (T_{des}) of 720 K give rise to slow hydrogenation/dehydrogenation kinetics. The consequence is that, for example 3000 s is needed for complete MgH_2 decomposition at 623 K [21]. Almost one third of accumulated hydrogen energy capacity is used for endothermic effect compensation of (de)hydrogenation reaction. Activation process i.e. continuous heating and cooling of metal in vacuum and in hydrogen atmosphere is necessary to form MgH_2 [22].

3.1 Destabilization of MgH_2 lattice

When kinetics limits formation and decomposition of hydride, various physical and chemical processes can be used to enhance MgH_2 formation by promoting destabilization of MgH_2 lattice or surface modification and/or structural deformation. Mechanical milling has favourable effect on a grains size and defects concentration, thus shortening the diffusion path of hydrogen through metal or hydride [23-26]. Another approach is an alloying, for example Mg_2Ni forms ternary hydride Mg_2NiH_4 which contains 3.6 wt% of H_2 . The hydride forms very quickly, probably due to Ni as catalysts of molecular hydrogen dissociation, but thermodynamics still imposes working temperature of 550 K at 1 bar of pressure [27]. Destabilization can be performed with various irradiation sources as well [28-32].

3.1.1 Improvement of MgH_2 properties by mechanical milling

Mechanical milling, performed under controlled atmosphere with mills for different proposes and design, is an effective way to activate solid reactants. Using this method, decreasing of grains and crystallites is obtained, as well as increasing of specific surface area. In addition to the surface modification of material, mechanical deformation is also present, reflecting in changes of crystal lattice microstrains and in a creation of defects, i. e. a creation of sites with lower activation energy which facilitate hydrogen diffusion through the matrix. An increasing of free energy of system allows overcoming of activation energy for the formation of metastable phase. High energy ball milling does not affect the thermodynamic properties of hydrides, which means there is no

change in length of isothermal absorption plateau $p = f(c)$ and there is also no significant change of hydrogen capacity in MgH_2 [33-35].

Nevertheless, Hout *et al.* showed that a number of improvements can be achieved with milling of pure MgH_2 at room temperature. Reducing the grain size, thus increasing of the specific surface area, is possible after 2 hours of milling, and formation of nanosized $\gamma\text{-MgH}_2$ metastable phase is also present. Particles of $\beta\text{-MgH}_2$ also become nanometer-sized (~ 12 nm). It is possible to decrease temperature of dehydrogenation for about 70 degrees, and also energy of activation for hydrogen desorption is decreased, from 156 kJ/molK for unmilled MgH_2 sample to 120 kJ/molK for milled sample [21].

Reactive mechanical milling or process of milling in hydrogen atmosphere is one more approach for MgH_2 hydrogenation/ dehydrogenation reaction kinetics enhancing and also for other materials based on MgH_2 . Comparing to the mechanical milling conducted in an inert atmosphere, this method has many advantages. First of all, releasing of heat during the high-energy collisions allows process of hydrogenation to happen at room temperature without additional heating; also, during the hydrogenation, new nucleation centers form and there is no formation of a continuous layer of the hydride phase on the surface, which would slow down further reaction. Thermal decomposition temperature decreasing for 10 degrees is very important feature of the reactive milling and the reaction rate is about 100 times higher compared to the mechanically activated magnesium [22].

3.1.2 Mechanochemical milling of MgH_2 with additives

Mechanical milling of MgH_2 with additives is the way to create composite materials and overcome some drawbacks of each individual component. Figure 6 shows schematically process of mechanical milling. Additives can be metals in elemental form (the most common transition metals), transition metal oxides, hydrides and organic compounds [23-27, 36].

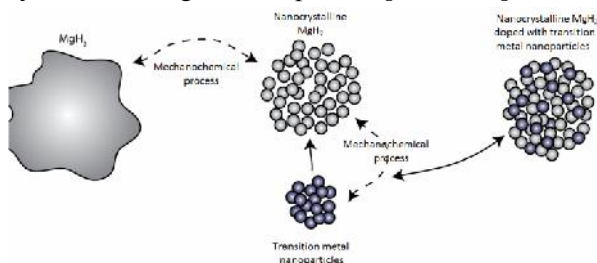


Figure 6 - Schematic representation of mechanochemical synthesis of composite

Shang *et al.* have shown both, experimentally and theoretically, that mechanically milled MgH_2 with

8 mol% of metal M (M = Al, Ti, Fe, Ni, Cu and Nb) has more or less improved effect on hydrogen desorption kinetics compared to milled MgH_2 without additives [36]. Another theoretical study shows that the addition of Ti and Co in an amount of 10 wt% leads to destabilization of MgH_2 . This is due to fact that Ti-H and Co-H bonds are stronger than the Mg-H bond leading to weakening of the bonds in the second and third coordination around Ti and Co atoms, which results in a destabilization of MgH_2 compound [37]. Varin *et al.* synthesized nanocrystalline hydride Mg-X (X = Fe, Co, Mn, B) and show that the hydrogen content is about 4 wt% H_2 at 579 K [38]. $\text{LiNH}_4/\text{MgH}_2$ mechanical milling leads to a decrease in the dehydration temperature to 473 K but with a very slow kinetics and the capacity decreased to about 4.3 wt% [39]. Oelerich *et al.* examined the catalytic effect of a large number of oxides Me_xO_y = Sc_2O_3 , TiO_2 , V_2O_5 , Cr_2O_3 , Mn_2O_3 , Fe_3O_4 , CuO , Al_2O_3 , SiO_2 and demonstrated that V_2O_5 and Fe_3O_4 showed the highest rate of desorption [40].

On the other hand Hammer *et al.* showed that the nanocrystalline Ni has a greater catalytic activity of the transition metal oxide for the dehydration reaction [41].

3.1.3 Destabilization of MgH_2 structure using ion irradiation

By ion bombardment it is possible to synthesize or modify materials [42]. It creates a large concentration of defects (vacancies, dislocations, micro-deformation), but also potentially implanted impurities in the surface layer of the material. It was shown that the surface and sub-surface layer plays a major role in the kinetics of hydrogen desorption from MgH_2 [28-32].

Information about defects in the material obtained by ion irradiation, can be estimated using Monte Carlo simulation program SRIM (Stopping and Range of Ions in Matter). SRIM is a group of software packages that gives the opportunity to calculate the parameters of the interaction of ions and solid targets using quantum mechanical approach. The calculations can be performed using statistical algorithms and the quantitative evaluation deals with the way how incidents ions lose energy and the question of their final distribution after stopping in the material. However, the calculations do not take into account the effects of crystal orientation nor provide data on the thermal effects in solid substances. It is possible to calculate: three-dimensional distribution of the ions in the solid and its parameters, such as penetration depth, its spread along the ion beam (called straggle) and perpendicular to it, all target atom cascades in the target are followed in detail; number of created Frenkel pair-

rs, concentration of vacancies, sputtering rate, ionization, and phonon production in the target material; energy partitioning between the nuclear and electron losses, energy deposition rate etc. [43].

Abe et al. use H^+ , Ar^+ and K^+ ions to improve sorption properties of mismetal alloys, and show that the samples bombarded with Ar^+ ions have a higher initial reaction rate of hydrogenation than the samples bombarded with H^+ ions. This can be explained by the fact that Ar^+ ions produce a higher concentration of vacancies which increase the number of active sites for hydrogen sorption. The bombing with K^+ ions proved to be the most effective, if we are talking about increasing the initial rate of hydrogenation. The authors explained this phenomenon assuming that there is a chemical interaction of the surface of the alloy with the implanted. It was shown that sorption reaction can be accelerated by increasing the ion energy and the fluence [44].

4. CONCLUSION

The main reason for the growing interest in hydrogen economy is the fact that hydrogen economy can be a solution to two major challenges that we currently face: climate change and the need for a secure supply of energy. Because of this it is necessary to develop new, highly - efficient energy technologies that do not emit carbon compounds or emission is very small. Also, a great need for alternative fuels, especially in traffic, further affect the increased interest in research in this area. In order to move from an economy based on carbon, which is now used, to a hydrogen economy, it is necessary to solve the existing problems related to the production, storage and security when handling hydrogen.

Of all possible solutions for hydrogen storage (gas cylinders, tanks for liquid hydrogen storage and solid-state storage), the most attractive and safest is one based on the storage in solid media, such as hydrides. Storing hydrogen in a solid state means storing hydrogen in form of metal/intermetallic hydrides and complex hydrides.

The release of hydrogen from the hydride is endothermic process. However slow sorption process, and high sorption temperature are problems to be solved in order to use hydrogen as an energy source. In order to overcome these shortcomings, in the past two decades both theoretical and experimental research were intensive. To improve the diffusion of hydrogen in metal hydrides various techniques such as mechanical milling and ion bombardment can be used. All these techniques lead to destabilization of MgH_2 lattice - through surface modification and structural deformation thereby reduction of particle size

and/or increase of the concentration of defects. Actually the main effect is shortening the time of hydrogen diffusion through the matrix. Also, fairly fast kinetics of hydrogen sorption is accomplished using metal, metal oxides, mainly transition metal oxides and transition metal as an additive in the process of mechanical grinding. In this brief review we have tried to summarize some of the results of the above mentioned methods of destabilization.

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REZIME

NAČINI SKLADIŠTENJA VODONIKA – IZAZOVI DANAŠNJICE

Glavni razlog sve većeg interesovanja za vodoničnu ekonomiju je taj što vodonična ekonomija može biti rešenje dva glavna izazova sa kojima se trenutno suočavamo: promenom klime i potrebom za sigurnim snabdevanjem energijom. Ali da bi se prešlo sa ekonomije zasnovane na ugljeniku na vodoničnu ekonomiju potrebno je rešiti postojeće probleme vezane za proizvodnju, skladištenje i bezbednost pri rukovanju vodonikom. Od svih mogućih rešenja za skladištenje vodonika (gasni cilindri, tankovi za tečni vodonik i čuvanje u čvrstom stanju), najatraktivniji način je skladištenje u čvrstim medijima, kao što su hidridi. Skladištenje u čvrstom stanju podrazumeva metalne/intermetalne i kompleksne hidride. Kako je oslobađanje vodonika iz hidrida endoterman proces, skladištenje u čvrstom medijumu je najbezbedniji način od gore pomenutih. Međutim spor proces sorpcije i visoka temperatura desorpcije su problemi koje treba rešiti kako bi se vodonik iz hidrida mogao koristiti kao energent. U prethodne dve decenije izvršena su mnoga kako teorijska tako i eksperimentalna istraživanja u cilju prevazilaženja ovih nedostataka. Spora termodinamika i kinetika sorpcije može biti promenjena destabilizacijom MgH_2 rešetke – modifikacijom površine ili strukturnom deformacijom. Da bi se poboljšala difuzija vodonika iz metalnih hidrida, koriste se različite tehnike kao što su mehaničko mlevenje ili jonsko bombardovanje, čime se postiže smanjenje veličine čestica, povećanje koncentracije defekata i skraćivanje difuzionog puta vodonika kroz matricu. Takođe, prilično brza sorpciona kinetika vodonika se postiže koristeći metale, metalne okside, prelazne metale i okside prelaznih metala kao aditive u procesu mehaničkog mlevenja. U ovom kratkom pregledu smo pokušali da sumiramo neke od rezultata gore pomenutih metoda destabilizacije.

Ključne reči: ekonomija bazirana na vodoniku, skladištenje vodonika, hidridi, kinetičke i termodinamičke osobine

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Vibration Measurements Using a Wireless Sensors Network

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Non-destructive structural health monitoring of civil engineering structures is based on vibrations measurements of objects during dynamic tests or during their exploitation. Wireless sensor networks are increasingly being used for this purpose. They make flexible and inexpensive measurement systems because large cables to connect the sensors are avoided. This paper presents a vibration monitoring wireless system developed at the Faculty of Civil engineering in Belgrade. The structure and characteristics of the measurement system, based on low consumption electronic components and original embedded software real time operating system, are described.

Key words: *wireless sensor networks, vibrations, accelerometers, data acquisition, low consumption*

1. INTRODUCTION

The developments in wireless technology, especially related to mobile telephony and the internet, have enabled the wireless sensor networks (WSN) to be used in many areas of science, engineering and everyday life [1,2]. Civil engineering is particularly suitable for WSN application, since it's much cheaper and simpler to employ such a system (compared to a wired one) on buildings, roads, railways, and especially capital objects like bridges and dams. The sensor devices are more easily placed on hard to reach spots and are more flexible than wired ones, meaning they allow for fast and easy relocation of the entire network or its parts. Most frequent objective of WSN use on civil objects is structural health monitoring (SHM), which includes recording the oscillations in different points, and gathering and processing the data to judge the structure condition [3-6]. Besides general requirements, a WSN needs to comply with specific

ones for use in civil engineering, like: resistance to extreme atmospheric conditions (high humidity, high and low temperatures), resistance to electromagnetic interferences (of both natural and artificial origin), placement of sensors on large dimensions objects, reliable communication between nodes in closed spaces (out of line of sight), etc.

Development of a wireless sensor network is multidisciplinary and includes: a) choosing or developing the sensors with low consumption, yet accurate enough for a specific application, b) design of the electronic circuitry with low consumption components, c) configuration of the wireless network so that it enables fast and reliable data flow between different nodes, d) development of flexible software to control the components and the system as a whole so that it can be used for a large variety of applications, e) development of processing software to be executed high level, for specific application in civil engineering or other target area.

2. HARDWARE

The wireless sensor network developed at the Faculty of Civil engineering, Belgrade, is comprised of sensor devices (nodes) placed at different measuring

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spots and a central (base) station. Each node contains a sensor (or multiple sensors), radio modem, battery, optionally with energy harvesting system, and accompanying electronics. Base station, which gathers and processes the data, is a standard desktop or a mobile laptop personal computer (PC).

Figure 1 shows a sensor device and its basic parts: main electronics board, board with the accelerometer, radio modem, and the housing with the antenna. Energy harvesting system and the display (not shown here) are optional. Base station has practically unlimited resources: it doesn't have to take care about energy consumption, processing power is big, and memory storage is practically indefinite for this purpose. All processing of the results except the compression prior to radio transfer, is performed at the base station.

Star network topology is used. Synchronization of the devices is performed by the beacon signal.

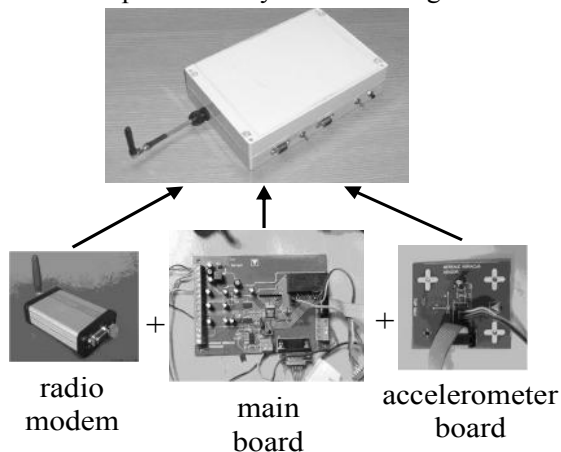


Figure 1 - Sensor device and its basic parts

2.1 Main board

The main board of a sensor node contains ADu-C845 processor and supporting electronic components. It's made using surface mount technology (SMT). The processor is a member of the wide 8051 processors family. 8051 type processors have long history of use in industrial applications and are considered very reliable. One of the things that make ADu-C845 suitable for particular application is relatively low consumption and the ability to enter so called sleep mode in which its consumption is about 70 μ W (neglectable compared to the consumption of stabilizers and other circuitry which is powered all the time). It works with programmable pace, which goes up to 6.292 MHz. It has two 10-channel 24-bit sigma-delta A/D converters built in, with effective resolution of 19.5 to 22 bits, and sampling frequency of 1 kHz, which exceeds usual needs in civil engineering measurements, and a thermometer with 1 $^{\circ}$ C resolution. The processor should be powered by 3-3.6 V voltage.

Stabilizers decrease input voltage which is normally in 3.5 to 4.1 V range (knee voltage to maximum voltage of 3 NiMH batteries) down to optimal 3.3 V. Working temperature range is -40 to $+85$ $^{\circ}$ C. Maximum current consumption is 4.8 mA (which corresponds to about 16 mW power). UART, I2C and SPI interfaces serve to connect the processor with all peripheral parts used in this application or potentially used in any similar one. The board also contains 4 LP2986 stabilizers, external 32 kilobytes RAM M4-8T35AV with its latch control circuit, ADR2981 reference voltage source, MAX3232 driver-receiver for serial communication, LT1512 battery charging controller, and a number of basic components such as operational amplifiers, diodes, oscillators, capacitors, resistors, etc.

2.2 Radio modem

Radio modem PRM-4 is an external device which is connected by RS232 interface to the main board. It is an independent processor device, which communicates with the board via RS232 on one end, and sends and receives electromagnetic waves using antenna of a variable size, shape and range, on the other end. Output power of the radio signal is programmable and this enables power saving in case large range is not needed. Maximum range in urban conditions is about 1 km, but it's dependent on artificial interferences and topology of the terrain. Baud rate of radio communication is 9600 bps and is performed at 863 MHz frequency. The modem consumes from several mA up to 40 mA during transmission.

Usual frequency of wireless modems is 2.4 GHz, but the carrier frequency of 863 MHz was chosen for better diffraction in closed spaces and less electromagnetic interferences (there is a larger number of wireless devices which work around 2.4 GHz).

The modem features its own protocol in which it uses CRC checksums and addressing masks. Similar methods are used by the embedded RTOS of the device node, so with two layers of control we can state that chance of receiving invalid data is nil.

2.3 Accelerometer board

The main sensor of the device is currently integrated microelectromechanical (MEMS) three-axial accelerometer LIS3LV02DL, with 12-bit resolution and the range of $\pm 2g$ (can be switched to $\pm 6g$). It communicates with the main board processor using 4-wire SPI interface. The accelerometer is placed on a separate plastic board which is powered from the common power supply (normally the batteries), so that it could be separately mounted, especially during the testing period. Sampling is performed using 160 Hz frequency (frequencies available are 40, 160, 640 and 2560 Hz), so that desired oversampling is achieved

for frequencies of interest in modal analysis of vibrations of big civil engineering objects, which usually don't exceed 25 Hz. One measurement lasts for approximately 20 seconds, during which time 3 times (for 3 axes) 3200 12-bit samples are acquired. The data is then compressed and sent to base station on its request using radio modem.

The experiments showed that sampling frequencies of the different accelerometer pieces, although nominally 160 Hz, aren't equal, and that they vary over 1%. That's one of the reasons why timestamping of the samples is important. Main purpose of this wireless system is modal analysis, which means oscillations in different points in space have to be compared, so relative time synchronization of samples gathered from different nodes is essential.

The program remembers start and end time of the approximately 20 second measurement. Relative time in which timers on nodes start their counting is the reception of beacon signal used to initiate the measurement cycle. Tests with storage oscilloscope have shown that standard deviation of propagation of this signal to different nodes is 6-7 μ s. Relative uncertainty of frequency of the oscillator running the main board processor can be over 10^{-5} , thus producing over 0.2 ms uncertainty in timestamps of samples near the end of a measurement period, and therefore being major cause of errors in data synchronization. But this situation may be mitigated using a number of techniques. Aged matching oscillators can be acquired with relative differences under 10^{-6} . Even if this is not done, test of the processors using a frequency counter may be performed, and the difference in measured frequencies can be used to adjust the data by software on the base station. The downside of this method is need for the test periodical repeating, due to the fact that crystals age and change their frequencies.

2.4 Display

Liquid crystal display D20486SYHLY is mounted on a separate integrated circuit, with the processor AT89C4051. This auxiliary board is placed into its own housing. It communicates with the main board using 2-wire I2C interface. Processor AT89C4051 doesn't have I2C protocol implemented, so all the coding was manually performed. LCD contains 4 rows by 20 characters and 8 buttons. Additional user-defined characters have been created.

The display can be optionally connected to the sensor device. Reasons for its use are multiple: it allows for easier development (debugging) of main board software, enables the diagnostics of node state in case it doesn't respond to radio signals, and serves for calibration of the device (setting the application para-

meters). Display board is powered by main power source, because I2C interface doesn't contain common ground. In case main power supply is empty, the display doesn't function.

3. ALGORITHM OF SYSTEM OPERATION

Sensor devices work in pulses. They spend most of the time in low consumption regime (sleep mode). Processor consumption in this regime is neglectable. Main source of consumption are stabilizers powering the processor (multiple stabilizers are employed for the purpose of precise A/D conversion in case external sensors are added to the device). They account for about 1 of about 1.5 mA (corresponding to about 5 mW) current consumption. Period of processor activation is programmable and can be anywhere between a second and 255 days (in practice, it should be expressed in minutes). Most peripheral components (most importantly the modem) are disconnected from the power supply while processor is in sleep mode. Upon activation, the processor turns the radio modem on, checks for the presence of radio signal from the base station, and if it isn't detected within several seconds, reverts to sleep mode. Base station starts periodically emitting beacon signal on the user request. This signal awakes and synchronizes the sensor nodes (measurement start is not ordered yet at this point). There are no guarantees that activation moments of nodes are approximately simultaneous, although in practice this will most often be the case, if the system is used actively. After the maximum time (defined by the user, preferably a little higher than expected period of node wake-up) has elapsed, or all requested nodes have responded, base station emits a beacon with the order to start the measurement process. All devices were in stand-by regime up to this moment, which means their awake periods have been extended to about a minute in anticipation of receiving new commands. After the measurement ends, devices go back to stand-by regime until they finish sending their data to the base station, when they go back to sleep mode.

4. SOFTWARE

Embedded real time operating system (RTOS) is software executed on the main board. Unlike the personal computer, where different layers of software exist, like the one written into the motherboard (BIOS), operating system (i.e. Windows), the application (i.e. a browser), and a script, macro, add-on, etc (inside the application), device of these dimensions and with fixed hardware configuration features static software. There is no possibility of loading different software modules during regular operation, so the whole set of routines, starting from most basic ones

like reading the keyboard or writing dots to the display, to most complex, like data compression, is integrated and called embedded RTOS. Development of this operating system was biggest item in creation of the system, not only for complexity of the tasks, but for the lack of expensive equipment enabling real time debugging as well.

Although there exists a main program, operating system also performs a certain level of multitasking. It takes care of interrupts from several different sources, such as timers, I2C interface and serial (RS232) interface.

Several events can cause processor wake-up from the sleep mode, and the program identifies source of the wake-up to choose the path of execution. Wake-up can be: a) due to power being turned on, b) after emergency termination (reset by the watchdog timer - this is not used in normal operation, only during the development and testing period), c) caused by attaching the display and pressing the wake-up button, or d) regular scheduled wake-up by timer. If the display has caused the processor wake-up, the device enters calibration mode. It displays basic parameters (temperature, battery voltage, cause of previous wake-up, wake-up interval, error flags, and miscellaneous other variables) and expects a further key press to enter the calibration (edit) procedure, in which user can view and alter many parameters or observe the output of the accelerometer. In all other cases, source of wake-up is saved into memory and the device awaits for beacon signal for a short period of time and then goes back to sleep.

External RAM memory (the processor also contains 256 bytes „DATA/IDATA“ memory and 2048 bytes „XDATA“ memory) saves the measurement results, since it has independent embedded battery, with guaranteed lifetime of 5 years (but previous experience with similar types showed that they can last for over 10 years). This way, measurement data can be retrieved even after the device has been shut down, for instance if there was an error in communication during buffer transfer. All auxiliary data is saved as well (physical date-time of the measurement, temperature, battery voltage and relative timestamps).

To save the energy during transmission of measurement results, it is necessary to compress the data. For this, a set of routines is written which perform standard generic Huffman coding of the signal which has already been differential pulse code modulated (DPCM). This lossless method typically yields 30-70% compression ratio for real vibrations, while noise can be compressed down to about 10% (this ratio depends on accelerometer noise magnitude which varies based on a number of factors). Ratio is calculated

using size of the data already packed into 12-bit fields (no unused bits).

Special challenge in application of this method is the fact that memory of the device is only 32 kB and half of this amount is already occupied by raw measurement data and other variables, so it requires rational use of resources and data overlaying. Overlaying means using same memory space for different variables which are not used in the same time. Recursive procedures necessary to create Huffman tree are time consuming so effective assembler programming is necessary in order to save time and achieve maximum energy saving. Typical compression takes several seconds (maximum compression for pure noise lasts well under a second using maximum 6.292 MHz processor tact). Compression time and ratio are, naturally, very dependent of the type of the signal.

A program for PC has been written to control the wireless network. This program controls the entire process by radio modem of the same type attached to the serial port. Prior to starting the process, user selects the devices he wishes to include. Then he „polls“ the devices, which means that PC sets its radio modem into proper regime and starts emitting „stand-by“ type beacon signals in approximately one second succession, and records if desired nodes respond to it. Nodes which wake up by the timer (regular scheduled wake-up) register this signal and enter stand-by regime. Time during which nodes are awake is normally set to about 3 seconds, to increase the chance of detecting broadcast signal, in cases when communication is not ideal (packets are lost). Nodes respond to each beacon during all the time it is being emitted from the base. Stand-by type beacon will stop being emitted once either all nodes included in the process have responded, or the time-out has been reached (predefined by the user). If all nodes responded, second beacon of a different type is emitted, to order the nodes to start the process. This process is either new measurement, transfer the results of a previous measurement, or the power test. Nodes not included in the operation will shut down upon reception of this signal.

Best synchronization is achieved if all nodes start their timers on the same beacon signal. Even in cases when perfect communication isn't possible and this doesn't happen, time between successive beacon signals can be recorded and post-facto correction performed on PC after the measurement.

If a new measurement is ordered, PC pauses for about 25 seconds to allow for measurement and compression. Data is acquired subsequently. All events are timestamped with physical PC time and written into a log which can be scrolled in the main window

or recorded into a text file. In case old measurement data is to be gathered, the only difference is that pause is skipped. Power test is performed so that a number of packets (with predefined content) is received from a single node for each transmission power and a percentage of successful transfers (as a function of power) is recorded. Additionally, just entering standby can be ordered too, in which case PC stops sending stand-by beacons and awaits for user input (nodes will wait for about a minute before they revert to sleep).

All functions can optionally set physical date-time on the nodes, their transmission power and wake-up period.

Measurement results can be viewed on the graphic, be saved to a binary file, or exported as text for analysis in other programs. Coefficients of cross-axial sensitivity can be written into the program and automatic correction of results can be performed before the export.

5. TRANSVERSE SENSITIVITY TESTING OF THE ACCELEROMETERS

Due to imperfections of MEMS sensors, there is cross-axial (also referred to as transverse) sensitivity, which means that output of the sensor for an axis is caused not only by acceleration in that direction but in two perpendicular axes as well [7]. Main source of this error is mechanical misalignment (non-orthogonality) of the plates which are pressed by the proof mass.

Output of the sensor can be described like:

$$\begin{aligned} f_x &= k_{x0} + k_{xx}a_x + k_{xy}a_y + k_{xz}a_z \\ f_y &= k_{y0} + k_{yx}a_x + k_{yy}a_y + k_{yz}a_z \\ f_z &= k_{z0} + k_{zx}a_x + k_{zy}a_y + k_{zz}a_z \end{aligned} \quad (1)$$

where coefficients k_{xx} , k_{yy} and k_{zz} describe main axial sensitivity and are dominant (much higher than others). k_{x0} , k_{y0} and k_{z0} are zero offsets and are sometimes omitted from the equation if it's assumed that direct component of the signal is neglected (in vibrations processing). Their determination is, however, included in the process of measuring other coefficients, and they are necessary to solve inverse equations and perform signal correction.

Transverse sensitivity testing is performed by so called tilt test, in which sensor is placed into different orthogonal positions (six of them), so that gravity acts on each axis in each direction. Due to imperfections of the surfaces and the housings, the sensor was rotated in each of the basic positions, and the results have been averaged. This eliminates effects of sur-

faces being sloped or sensors being not perfectly adjusted to the housings. Experiments without any external equipment yield results repeatable down to several % and confirm that highest cross-axial sensitivity, defined as:

$$\begin{aligned} S_{cr.x.} &= \sqrt{k_{xy}^2 + k_{xz}^2} / k_{xx} \\ S_{cr.y.} &= \sqrt{k_{yx}^2 + k_{yz}^2} / k_{yy} \\ S_{cr.z.} &= \sqrt{k_{zx}^2 + k_{zy}^2} / k_{zz} \end{aligned} \quad (2)$$

equals 2.8%, which satisfies the manufacturer's specification (up to 3.5%).

6. EXAMINATION OF TIME SYNCHRONICITY OF MEASURED DATA

Simultaneity of beacon signal reception on different nodes has been examined with a storage oscilloscope. Two sensor boards were programmed to flip a digital output pin signal of a processor upon reception of the beacon. These pins were connected to two oscilloscope channels. One signal edge was used to trigger the oscilloscope and the shift in time of two edges was observed. Each edge had neglectable rise and fall time (far under a microsecond) and software detection of the signal causes additional uncertainty about a microsecond. Results show standard deviation of 6-7 μ s with maximum value of 20-25 μ s from several hundred experiments. They vary slightly when different pairs of nodes are examined.

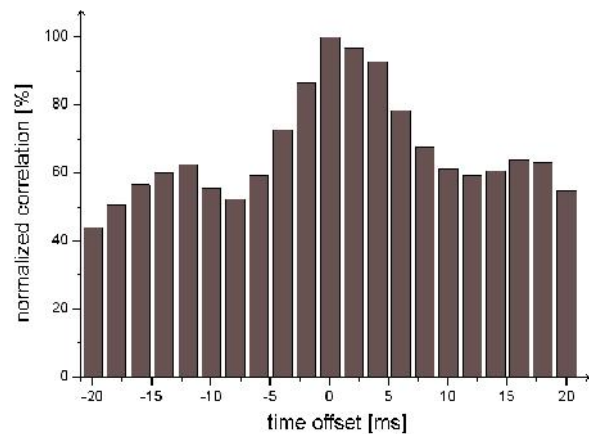


Figure 2 - Normalized average cross-correlation function of two recorded signals as function of time shift

In the next experiment, 36 measurements were made using two accelerometers attached as near as possible (under 10 cm) to the common plastic pad. The pad was placed on the surface and exposed to different types of vibrations. To check the concurrence of the signals, their cross-correlation function

was observed. Since samples from different nodes are not simultaneous (measurement points in time are not identical and differ within sampling period range), results from one sensor were linearly approximated (based on adjacent samples) so that their timestamps match the other. Direct components of both signals were removed and data from two sensors were multiplied. If the timestamps from sensors are correct, correlation function should peak when time offset of one signal compared to the other equals zero. In reality, this can not always happen due to the facts that sensors don't record exactly the same signal since they can't be placed to exactly the same position, and their dynamic characteristics can't match perfectly. Deviations naturally occurred in these experiments. Overall result is satisfying as shown in histograms in figures 2 and 3. The first one shows cross-correlation in relative units averaged for all measurements. In some measurements, time shift of maximum correlation is zero, while in others it's not. This can not be observed in figure 2, so the figure 3 shows distribution of time offsets for which the maximum is achieved. Step in the analysis was 2 ms, which equals one third of the sampling period.

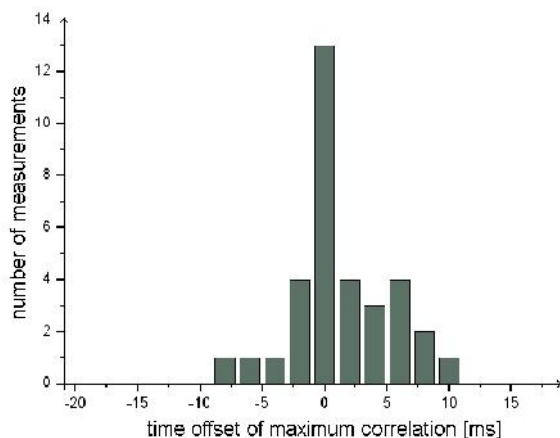


Figure 3 – Time offset of maximum cross-correlation

7. RANGE EXAMINATION

Modem range is a term which is impossible to define precisely. Probability of data packet transfer depends on its size, power of the transmission, distance between the transmitter and the receiver, types of antennas, obstacles (shape, size and position), atmospheric conditions, natural and artificial interferences, etc. Number of retries increases the chance of success. In case of sensor nodes with limited power supplies, it is necessary to choose the number of retries so to achieve compromise between the chance that a desired number of packets (ranging from 10 to 30 at 160 Hz sampling frequency in practice) is successfully transferred, and the power saving. Not only do transmission retries deplete energy reserves of a

node transmitting its buffer, it also drains other nodes which have yet to transmit the data, since they are in stand-by mode until their turn to transfer the data comes. The base station software allows the user to choose maximum number of packet retries.

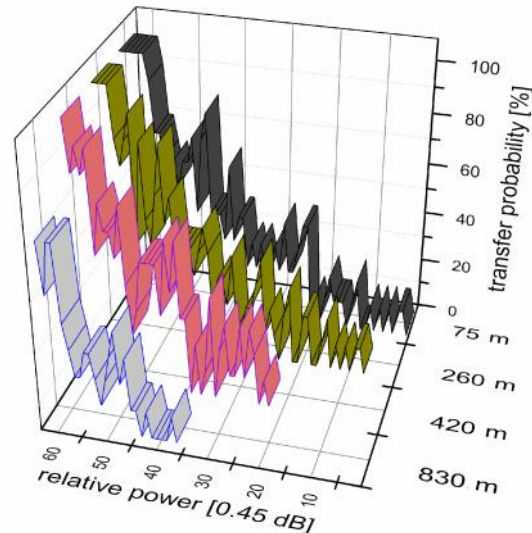


Figure 4 – Packet transfer probability as a function of transmission and the distance

This experiment shows the probabilities of packet full of different bytes (250 characters length) is transferred using different transmission powers of a sensor node on different distances from the base station. Ten packets were transmitted for each power, which can be adjusted in 64 steps, so 640 packets were emitted in total on a single distance. Maximum power of the transmission equals 20 mW and is equivalent to power parameter being equal to 63, and each decrement by 1 corresponds to -0.45 dB (so that zero relative power equals about 30 μ W). Series of experiments showed that results do not vary as a function of supply voltage (ranging from 3.55 to 4.05 V, modem being powered directly by batteries and not through the stabilizer). However there are considerable random variations (significant drops in the rate of transferred packets) in different times of a day, which is contributed to artificial interferences. Measurements have been performed under the conditions of heavy traffic on a busy city boulevard, and the base station was located in the building of the electrical faculty. Figure 4 shows several (for clarity reasons) examples of relatively satisfying results. Conclusion is that modem range can be declared to be about 800 m in the line of sight, in the city center.

8. CODING

Performing a series of experiments on low powers, it soon became obvious that some packets (certain data contents) have higher chance of being transferred than others. Reason for this occurrence is mo-

dem internal imperfection. In order to improve efficiency the coding was introduced. Results were satisfying.

If the transfer fails on the first attempt, nodes perform coding, and that is exclusive or (xor) operation with an 8-bit key (byte composed of different bits, such as 10101010, 11001100, etc). This byte is generated at the base station and transmitted as a parameter to the nodes. Decoding (another xor with the same key) is performed when the packet is received. Number of retries is programmable and each retry uses a different key.

It is not unreasonable to suppose this method could be employed with variable success in other cases where a constant bit rate has to be used, and there are different physical sources of disturbances in the process of signal transmission, because the coding changes number and distribution of bit transitions (0-1 or 1-0) and therefore influences spectrum of the signal, regardless of the modulation type used and the physical nature of the signal. Similar methods are usually described as data whitening [8].

9. CONCLUSION

A wireless sensor network for vibrations measurement on big civil engineering structure was developed and described in this article. It's composed of sensor nodes with three-axial accelerometers and a central station. Special care was taken to minimize energy consumption because of battery power supply, by choosing components with low consumption and optimal software management.

Due to original embedded real time operating system, it is possible to vary a large number of parameters, thus adapting the network to conditions of a specific measurement task. Cross-axial sensitivity of accelerometers was examined and corrected.

Time synchronicity of data from different nodes was examined and methods to improve it were introduced. Power test was designed to estimate transmission power needed for transfer of the measurement data. Efficiency of the data transfer was improved by coding (data whitening).

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REZIME

MERENJE VIBRACIJA MREŽOM BEŽIČNIH SENZORA

Nedestruktivno praćenje stanja građevinskih objekata se bazira na merenju vibracija objekata pri dinamičkim ispitivanjima ili u toku njihove eksploatacije. U ovu svrhu se sve više koriste mreže bežičnih senzora koje čine fleksibilan i jeftin merni sistem, jer nema razvlačenja kablova velikih dužina za povezivanje senzora. U ovom radu je opisan sistem za bežično merenje vibracija na objektima razvijen na Građevinskom fakultetu u Beogradu. Predstavljeni su struktura i karakteristike mernog sistema baziranog na elektronskim komponentama male potrošnje i originalnom softveru.

Ključne reči: bežične mreže, vibracije, akcelerometri, akvizicija, niska potrošnja

Smart homes

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As a result of limited energy resources, and environmental disturbances caused by increasing overall power consumption, rationalization imperative of that consumption is imposed. Different ways to save energy consumption occur.

Terms of intelligent network and intelligent home are increasingly common in the literature. For the realization of smart homes is necessary to ensure the ability to manage terminal devices, and home and office appliances. With intelligent networks introduction, remote control of all devices in the network is possible, and devices are able to receive remote signal and respond to it.

Key words: energy efficiency, energy consumption, intelligent buildings, intelligent local networks

1. INTRODUCTION

Term *Smart Home* covers all types of buildings, residential and commercial, which are equipped with intelligent network functions, at a bigger or smaller extent. In business and larger residential buildings, the networks are further expanding on the basic units, commercial and residential. In these structures each such unit represents a separate consumer entity for the intelligent network [1].

A short definition of intelligent building term could be "more comfort with less energy consumption", with main accent on the thermal and electrical energy. These two types of energy are inextricably linked, since a significant part of the electricity consumption belongs to the functions of maintaining the rooms' temperature, i.e. on heating or cooling.

The indoor temperature maintenance depends on several different factors, which can be divided into the one non dependent on space users, and others who are directly dependent on their habits and desires. The first group primarily depends on the construction characteristics of the buildings, particularly of thermo insulating parameters of walls, doors and windows. These characteristics can be considered as constant, and their improvement require greater investments.

Second group of factors that affect energy consumption, and which depend on the users' habits and

desires, includes not only indoor temperature control, but also number and nature of other electrical devices (particularly those with power consumption above 1 kW), as well as time and frequency of their usage. Optimal compromise between keeping the desired users' comfort and rational energy consumption can be achieved by implementing measurement and regulation sets, which represent an inevitable content of intelligent buildings [2].

2. SMART HOME FEATURES

The term smart home implies integration of all electrical and electronic devices through communication network, in order to control the entire household from one place that can be a distance away. The idea behind this is to simplify use of home appliances, enhance their functionality, increase comfort of household members, as well as reduce the overall energy consumption.

Intelligent network refers to electricity networks which are, as a whole or in its parts, improved to increase energy efficiency of the system, and to enhance quality and reliability of electricity distribution. One of the necessary conditions for evolution of electrical to intelligent networks status is to create an adequate telecommunications infrastructure. This infrastructure should include all entities in power systems in the areas of generation, transmission and distribution of electricity, as well as all consumer entities [3], [4]. Intelligent buildings as consumer entities in intelligent networks are analyzed, in a first step.

In a process of intelligent network realization, one of the main problems is inclusion of all consumer

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entities, as a result of their large number. As an example, it can be stated that in larger urban areas, number of power consuming facilities is in a range from a few hundred to a few thousand, while number of consumer entities is between tens of thousands and hundreds of thousands. The fact that each of these entities should be properly included in a system indicates that finding optimal technical and economical solution for segments of telecommunications infrastructure is a task of primary importance [5].

3. MEASUREMENT AND REGULATION SET

3.1 Structure

Measurement and regulation set (hereinafter MRS) is a functional unit, which performs all monitoring, metering and control functions in consumer's entity, which are defined within a given intelligent

network. Like any system of such designation, MRS contains following elements:

- Local intelligent network processor with interfaces for internal and external communications;
- Internal communication network;
- Measurement and status sensors on all monitoring, metering and control units;
- Actuators on control units.

Figure 1 shows principal block diagram of a local network for a smart home.

All sensors in monitoring units, actuators in control units, as well as all the other terminal electronic devices require power supply for functioning in on-line mode and stand-by mode. This way of functioning consumes additional electricity.

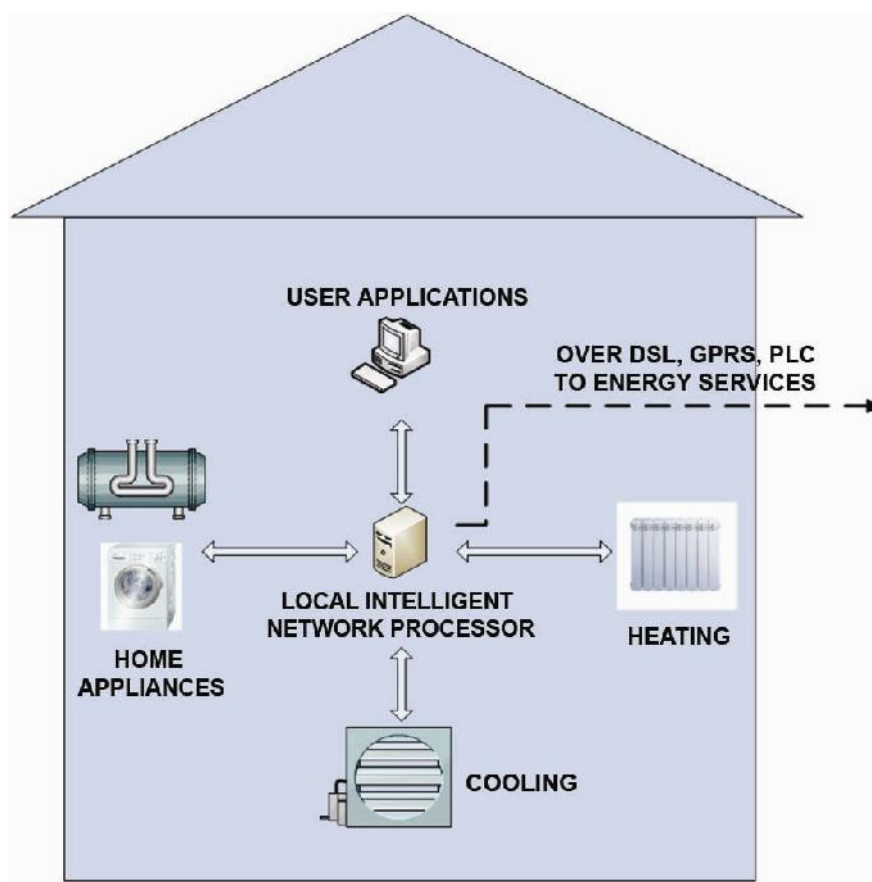


Figure 1 - Block diagram of local communication network in Smart Home

3.2 Services

Within a smart home concept, following services can be provided:

- Households' protection by management and control of window and door detectors, motion detectors, video surveillance systems, fire sensors, gas and water leakage detection.
- Management of household appliances - switching lights on and off, garage door opening and closing, programming of refrigerators, washing machines, microwave ovens, TVs and PCs.
- Energy savings - depending on weather conditions it is possible to regulate temperature; depending on brightness it is possible to turn lights on

and off and depending of CO₂ concentration to turn on and off ventilation. It is also possible to turn on and off domestic appliances as needed.

- Load control of power grid by companies engaged in generation and transmission of electricity.
- Noise level reduction ("ripple control") in power grid, which is very important for applications such as switching tariff rates of metering devices (day and night tariff), public lighting control, turning on and off consumer groups from power grid.

Further discussion in this paper focuses on functions for energy efficiency achievement, which can be regarded as particularly significant. A significant portion of total heating and electrical energy consumption goes just to maintain room temperature, i.e. heating or cooling, which means that network should encompass all relevant components of installations.

3.3 Temperature regulation

In contemporary residential unit of medium size, which is included in remote heating system, number of radiators is typically between 6 and 9. To measure heating energy consumption, an appropriate device has to be installed with every radiator. That device is a heating cost allocator. Furthermore, for maximum efficiency, it is necessary to install radiator thermostatic valves, so users can adjust temperature of each room separately.

Energy consumption data can be read locally, on each radiator, but remote reading is much cheaper and more comfortable for users. In this case, measurement results are transmitted to local network processor, where they are processed and forwarded to operators of remote heating system.

Further monitoring of heating regimes in apartments includes electro thermal devices, especially air-conditioners, which also need to be involved in a data acquisition network. Finally, various other data are useful, such as room temperature, status of open window sensors etc.

Presented review shows that in an average residential unit, fully equipped for "smart home" regime, number of different sensors can be up to twenty or more. Also, the fact that these sensors are approximately evenly allocated around household is important. These facts require design, planning and implementation of internal communication network to be quite complex tasks.

4. INTERNAL COMMUNICATION NETWORK

Smart Home concept is still under development and expansion phases, although strong growth is predicted. Current solutions use GSM and POTS / ISDN modems to form telecommunications networks for data transmission. Figure 2 shows Smart Home system implemented in this way. In the near future, power network will be used as data transmission network. Its advantages are cheaper and easier management and maintenance.

Also, power network is fully scalable and flexible, and easy to utilize for users with small technical knowledge. Spatial network distribution, and large number of access points at home (electrical outlets) are distinct advantage of this technology. Figure 3 shows a general block diagram of Smart Home system with PLC and Figure 4 shows Smart Home services that can be realized through PLC.

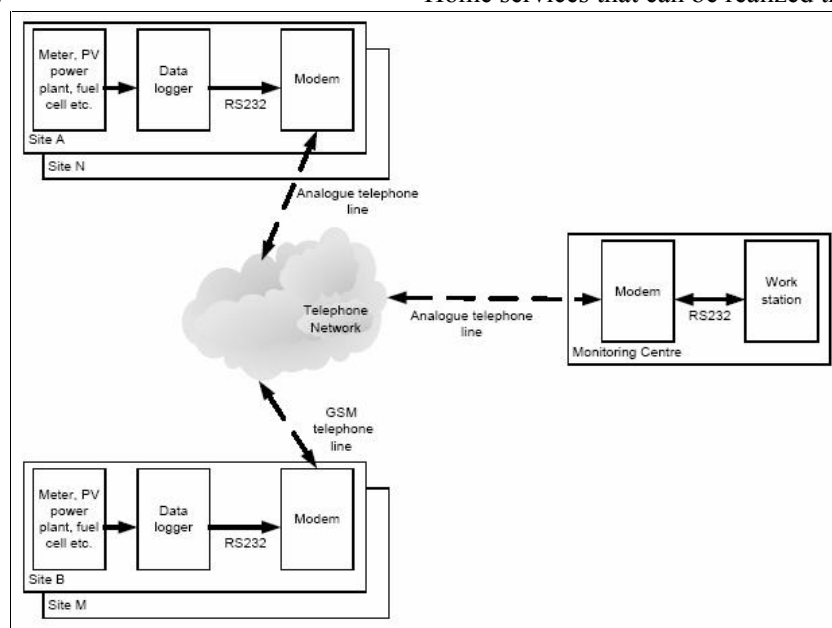


Figure 2 - Smart Home system with POTS and GSM network

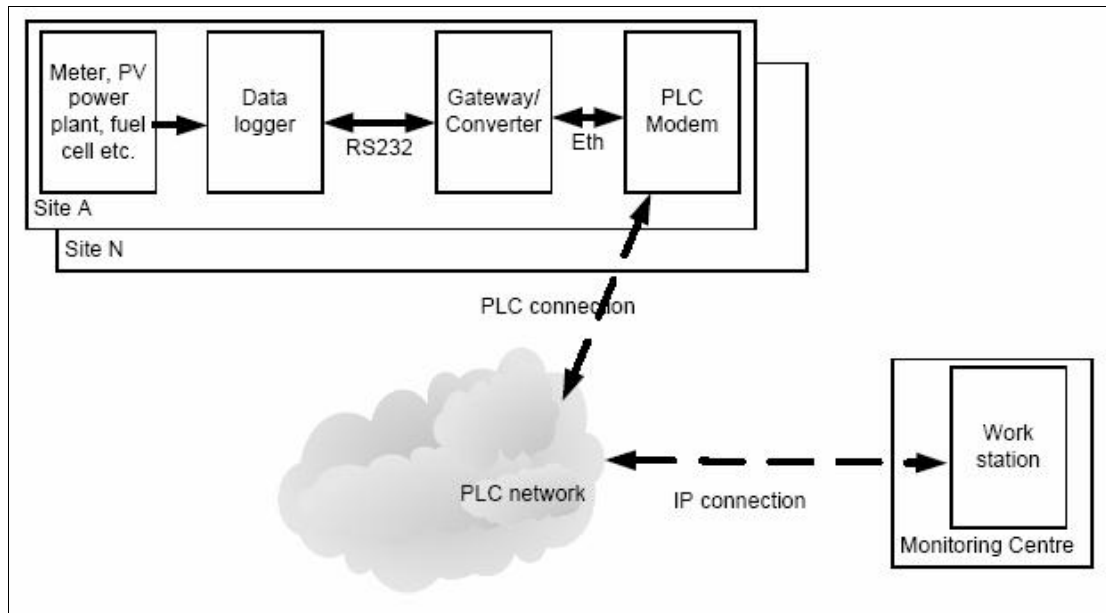


Figure 3 - Smart Home system with PLC network

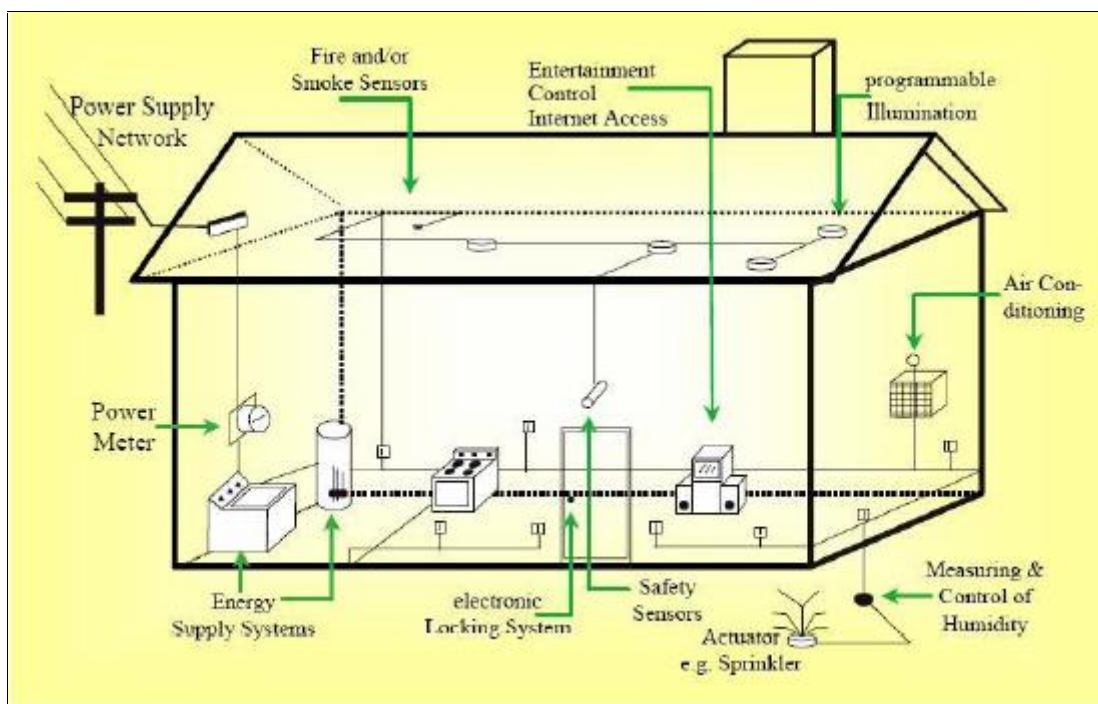


Figure 4 - Smart Home services realised by PLC network

Sensor signal acquisition and signal transmission functions toward executive units require adequate internal network. Next to each sensor, executive unit and other necessary equipment, an appropriate terminal device must be installed. Through this device connection to a local network processor can be established.

In today's residential units, number of terminal devices can vary in a quite wide range. Various household devices labeled "ready for smart home" are

already present in markets, which suggest further networks' expansions and appearance of new functions in CCCB (commands, controls, and communications in buildings) services set [6].

In local network design it is necessary to define basic initial settings:

- Characteristics of transmitted signals, and
- Communication characteristics of processors and terminal devices.

In almost all networks of such purposes, communication between processor and terminal takes place in polling regime with signal transmission in reverse simplex. Elementary communication segment between processor and terminal includes polling processor message, terminal's acknowledgment and two protective intervals. In such networks, average equivalent information content of an elementary segment is around $Q_1 = 240$ bits. Total equivalent content of cycle Q_C can be expressed as:

$$Q_C = n \cdot Q_1 [\text{bits}]$$

where n represents number of terminals.

Based on total equivalent information content and reading cycle period, it is possible to determine necessary binary rate in a network, R :

$$R [\text{bit/s}] = Q_C [\text{bit}] / t_C [\text{s}]$$

where t_C is a reading cycle period. For listed average values of relevant quantities it is implied that required binary rates are within limits of 100 - 250 [bit / s].

Network processor performs a network communication router function, which means that processor is transparent to various forms of communication. Wireless connectivity is, from an installation point of view, somewhat better, but it shows a serious limitation in a transmission distance range - in large buildings it is within limits of 10 - 20 meters [7]. Wired transmission has not such restrictions, but it requires appropriate cabling across entire residential unit. As an optimal solution, power lines transmission, is reviewed and further analyzed, in a standard frequency range between 90 - 150 kHz [8], [9].

Power lines installation are necessarily present in every room, and all lines are crossing switchboard of residential unit. This means, in order to connect an allocator to a network, just a short wire segment needs to be laid to nearest outlet. Local network node is typically next to a switchboard of power line installation. Signal transmission through power lines installation is done by N and PE conductors, which means there is no risk of adverse interactions.

For proper design of this signal transmission concept, it is necessary to analyze communication and transmission characteristics of power lines.

5. SMART HOME SYSTEM BENEFITS

Smart home concept exists, according to some authors, for decades. Given a current trend of reduction of total energy consumption, due to a lack of energy, and constant increase of energy price, this system becomes more important. All electronic devices consume some power, even in switched off mode (laptop, audio systems, televisions, etc.) and that con-

sumption may be significant percentage of total consumption [10].

Smart home allows devices to be turned off by customer request, regardless of user's location. In addition, system allows for certain devices to be turn on / off at a certain scenario. With proper use of smart home system, savings of up to 50% per month (for energy) can be achieved.

With technology and equipment development, there are plenty of such systems in a market. A special contribution to these systems is made by ICT technologies, primarily communications, which are able to connect many different devices.

Smart home systems, in addition to significant energy savings, provide home environment control comfort, and enable certain safety and security (e.g. turning off electricity when we are not at home, or apartment surveillance, or applying a particular "not at home" scenario etc.).

Smart home system, in terms of benefits it offers, can be viewed in three ways: American vision is to enable multimedia and comfort, European vision emphasis energy saving and Russian vision where safety is primary issue. We can conclude that Smart home provides all three aspects.

6. CONCLUSION

Smart home system is becoming more popular, while energy is becoming more expensive, and classical energy sources do not meet the needs of both, resources and ecological requirements. System is becoming indispensable element in a construction of commercial and residential buildings - as already stated before, saves energy, provides additional comfort and increases safety.

In a smart home system, electronic and electrical devices are connected through communication network, and telecommunications infrastructure is of a major importance. However, an important role is played by local intelligent network processor, that can perform a specific computer adequately equipped with hardware and software.

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REZIME

PAMETNE KUĆE

Kao posledica ograničenih energetske resursa, kao i ekoloških poremećaja izazvanih sve većom opštom potrošnjom energije nametnuo se imperativ racionalizacije te potrošnje. Pojavljuju se različiti načini za uštedu potrošnje električne energije.

U literaturi je sve prisutniji pojam inteligentne mreže i inteligentne kuće. Za realizaciju inteligentnih kuća je neophodno da se obezbedi mogućnost upravljanja terminalnim uređajima, odnosno kućnim i kancelarijskim aparatima. Uvođenjem inteligentnih mreža ostvaruje se daljinsko upravljanje svim uređajima do kojih stiže komunikaciona mreža, a uređaji imaju mogućnost da prime daljinski signal i odgovore na njega.

Ključne reči: *efikasnost, potrošnja električne energije, inteligentne zgrade, lokalne inteligentne mreže*

TECHNICS

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Ventilation Planning and Design of the Derin Sahalar Mine

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This paper describes a case study for the ventilation planning at TKI Company's Derin Sahalar Mine in Tuncbilek coal basin which is located in Kutahya region in central Turkey. Planned production of Derin Sahalar mine is 3.0 million tpa of coal. This should be achieved with four mechanized longwalls and two manual-semi mechanized longwalls. Designed ventilation system for the mine operations and production was determined by development of ventilation model based on data collected during a site visits. The paper discusses the challenge to coordinate necessary ventilation requirements with long-term demands. A diagonal mine ventilation system configuration was recommended according to the results of the network modeling exercise of the various options. The scope of the configuration changes and the improvement resulting from these changes is discussed.

Key words: mine ventilation planning, underground coal mining

1. INTRODUCTION

The contemporary mining theory and methodology of mine ventilation planning and design and practice is quite different in comparison to traditional approach. Possibilities enabled by computer hardware and software are used by modern approaches to the full advantage. Software packages for mine ventilation simulation are now gaining more importance in the process of mine ventilation planning and design [4-8].

Data acquisition is the first phase of this approach. Therefore, new mining practice are including detailed investigations of ore deposits in order to collect as much information as possible for the planning and design of deposit's mining technological system.

Introductory activity for the design process is system planning. This phase includes identification and taking into account the key relations that have importance for the design phase. Initial activity in the mine

ventilation planning and design process is the development of a basic or initial ventilation network with the suitable database with all required data, which are related to this network. Design process is followed by the implementation of the mine ventilation system as well as its maintenance, aimed at securing the highest possible level of system effectiveness.

The final phase in the outlined approach is evaluation of mine state and its possible modification. All parameters of mine ventilation obtained through monitoring must be compared with designed parameters and when differences are identified, specific changes have to be made in the planning process.

Chapter 2 of this paper provides the general description of the Derin Sahalar mine design. The proposed mine ventilation concept of Derin Sahalar mine is described in chapter 3.

The results of performed calculations on required amount of air for mine ventilation are presented in chapter 4. The analyses of Derin Sahalar mine ventilation design scenarios is discussed in chapter 5, followed by a conclusion in the last chapter.

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2. GENERAL DESCRIPTION OF THE MINE DESIGN

Team of the experts from the University of Belgrade, Faculty of Mining and Geology, have developed conceptual design of the underground coal exploitation in Derin Sahalar deposit from Tuncbilek coal basin which is in Kutahya region in central Turkey.

Retreat longwall mining is designed for coal production. Existing reserves in Derin Sahalar deposit are 78.79 million tons, and 73.28 million tons will be

mined by fully mechanized longwall method of work with top coal caving (LTCC).

Remaining reserves of 5.51 million tons will be mined by semi-mechanized longwall method, using drilling and blasting and individual friction props. This approach is recommended in order to increase recovery and reduce coal losses in Derin Sahalar deposit.

Also, Derin Sahalar deposit is heavily faulted, meaning that mechanized longwall mining is not possible in small blocks (figure 1).

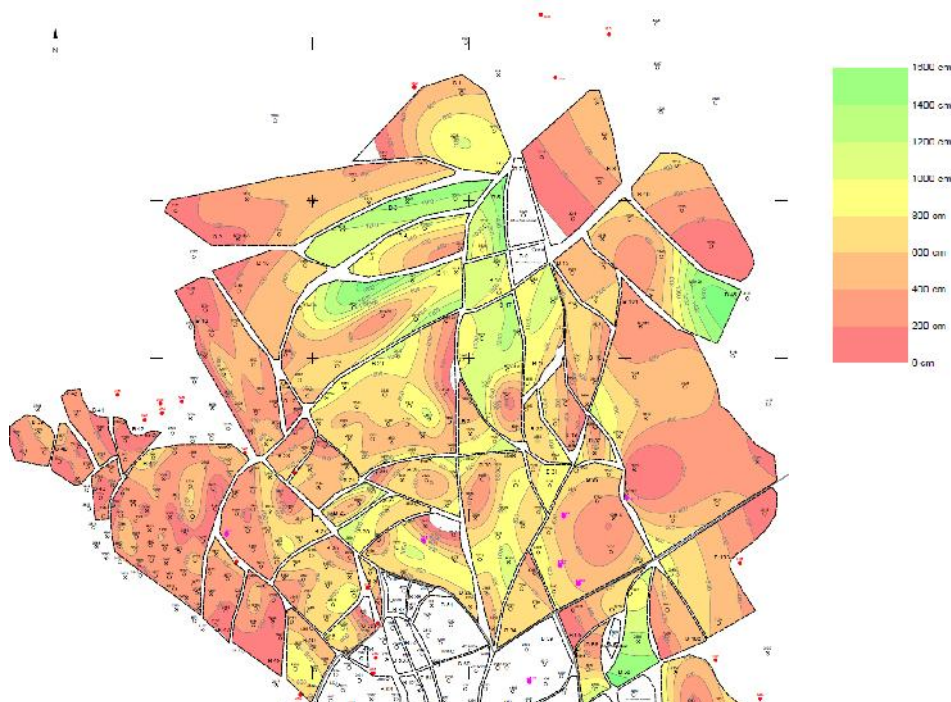


Figure 1 - Thickness of workable coal in blocks of Derin Sahalar deposit

Faulting and inclination of blocks restricted mine design in such manner to optimize complete mining process as well as costs for mine opening and production, within the Derin Sahalar mine life of 28 years. This paper provides detailed insight to ventilation concept and design of Derin Sahalar mine in consideration of described restrictions.

3. MINE VENTILATION CONCEPT

Ventilation of coal production, after proposed concept of mine development and coal mining in Derin Sahalar exploitation field, will be organized as presented on figure 2. Combined ventilation circuit and auxiliary ventilation of underground roadways will be implemented for ventilation of mining activities during coal exploitation.

Mine ventilation is designed in compliance to standards for gassy mines. Directions of intakes and returns airflows are shown on figure 2. As it can be

seen, suggested concept is based on exhaust ventilation; meaning that return air will ascend to the surface.

Suggested solution can be categorized as central ventilation system. This system has some advantages, such as fast establishment of main ventilation airflow and reduced investment works.

Disadvantages of central ventilation systems are:

- long routes for ventilation air,
- large differences in ventilation pressures (heads) by phases during mining near the boundaries of the deposit or during mining in proximity of opening roadways,
- larger probability of air losses and more complex measures for their prevention,
- higher ventilation pressures (heads) and
- increased operational costs associated to ventilation.

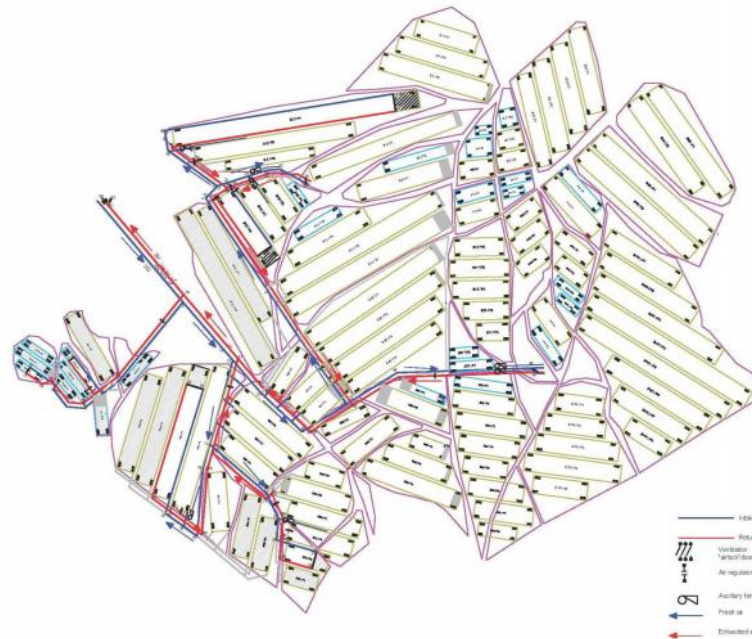


Figure 2 - Derin Sahalar mining field ventilation concept

It is suggested to develop main vent decline from the East (Figure 3) after the 12th year which will be active until the end of coal production in Derin Sahalar mine. Positioning of main fan at the opening of this roadway at the surface would enable establishment of diagonal system of ventilation.

Advantages of this approach are:

- proportionally constant ventilation pressure differences (heads) in longer periods of production or with smaller variations. This would result in increased safety and improved economics,
- smaller absolute values of required ventilation pressure (head),
- significantly reduced possibility of air losses,
- easier management of air distribution and fewer required flow regulators,
- easier isolation of parts of the mine, when necessary,
- reduced operational costs associated to ventilation.

These remarks are significant since Derin Sahalar mine will operate as gassy mine including the fact that existing experience in Ömerler A mine is showing that coal is liable to spontaneous combustion.

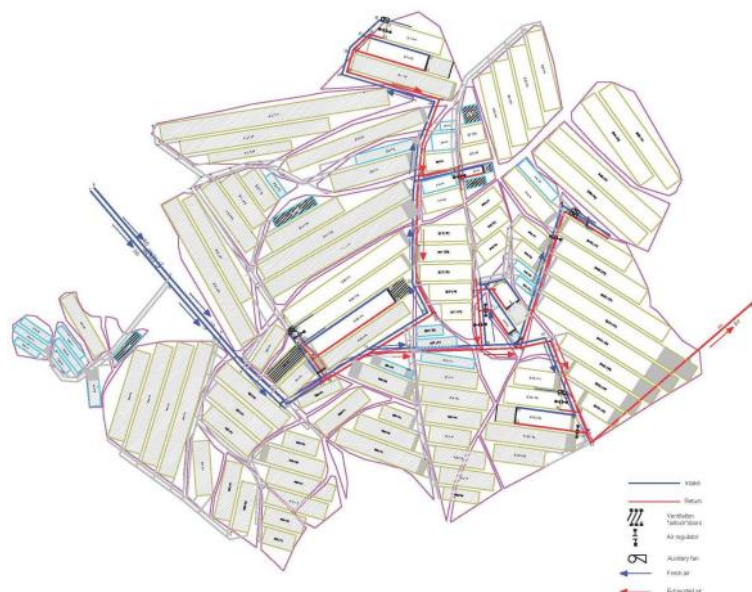


Figure 3 - Ventilation concept with East ventilation decline

4. REQUIRED AMOUNT OF AIR FOR MINE VENTILATION

Criteria applied for calculation of required amount of fresh air for one mechanized longwall is [9]: intensity of dust emission at the longwall face and minimal allowed air velocity, required for taking out gasses and dust.

Required amount of the air according to the significant criterion of dust emission can be determined according to:

$$Q_{LW} = \frac{I}{n_{risk} - n_0} \times k_v \quad [m^3 / \text{min}]$$

where:

Q_{LW} – required air quantity for longwall ventilation, m^3/min ,

I – intensity of dust emission, mg/min ,

n_{risk} – concentration of dust by level of risk, mg/m^3 , [1-2],

Dust risk grading	Respirable dust concentration (mg/m^3)
I	0 - 2.5
II	2.6 – 6
III	6.1 – 10
IV	>10

n_0 – dust concentration in the inlet, mg/m^3 ,

k_v – coefficient of dust emission variation, ($k_v=1.1 - 1.3$).

Value for specific dust emission must be less than 2 g/t to keep the risk within boundaries of second risk level. This corresponds with recommended value in references and practice. Intensity of dust emission will be 4.7 g/min at longwall production faces. Such approach is accepted since there is no available data on dust emission (I) for different conditions and rocks in Derin Sahalar mine. Required amount of air for ventilation of longwall, with this data, will be:

$$Q_{LW} = \frac{4700}{4.3-0.2} \times 1.1 = 12609 m^3 / \text{min} = 21 m^3 / s.$$

Amount of fresh air for a single manual longwall is calculated according to following criteria: intensity of dust emission at the longwall face, minimal allowed air velocity required for taking out gasses and dust and maximal amount of explosive detonated in one blasting.

Criterion on minimal air velocity includes minimal velocity necessary to generate turbulent flow of air in order to prevent bedding of gasses and creation of unventilated zones. Accepted air velocity is recommended value of 1.5 m/s – velocity required for

scuffing respiratory particles (1-2 m/s, NIOSH IC 9465, [3]), since this mine has non-methane conditions. Regarding criteria on minimal air velocity necessary amount of air for single manual longwall face would be:

$$Q_{LW} = A \times w_{\min} = 6.0 \times 1.5 m^3 / s = 9 m^3 / s.$$

Total amount of fresh air required for ventilation of the Derin Sahalar mine must be sufficient for four mechanized longwalls, two manual longwalls, 4 longwall development roadways and 3 mine development roadways, or:

mechanized longwalls: $4 \times 21 m^3 / s = 84 m^3 / s$,

manual longwall: $2 \times 9 m^3 / s = 18 m^3 / s$,

longwall development roadways:

$$(4.5 m^3 / s \times 1.3) \times 4 = 23.2 m^3 / s,$$

mine development roadways:

$$(4.5 m^3 / s \times 1.3) \times 3 = 17.4 m^3 / s,$$

air losses on entrance:

$$(2 \% \text{ of total air quantity}) 2.8 m^3 / s,$$

TOTAL: $Q_{\text{tot}} = 145.4 m^3 / s$.

5. ANALYSES OF DESIGN SCENARIOS

Coal mining at mechanized longwall panels B44/P2, B49/P2, B10/P4 and B2/P1, together with mining at manual longwall B40/P1 and B39/P1, with active development faces in panels B44/P1, B49/P3, B10/P3 and B2/P2 and roadway developments at elevation 255 m, 280 m and 217 m was first considered scenario for definition of ventilation parameters of Derin Sahalar Figure 2).

Results of conducted calculations on aerodynamics resistances in branches are shown on figure 4 Canonical ventilation scheme of the analyzed mine ventilation - scenario 1. Formula used for calculation of aerodynamics resistances of roadways is:

$$R = k \times (L \times U / A^3) [Ns^2 / m^8]$$

where: k – aerodynamics friction coefficient, kg/m^3 , (Hartman 1997, McPherson 1993); L – length of the roadway, m; U – perimeter of roadway, m; A – cross-section area of the roadway, m^2 .

Formula used for calculation of pressures of roadways is:

$$h = R \times Q^2 [Pa]$$

where: Q – air flow volume through the roadway, (m^3/s).

Distribution of node pressures in ventilation network is shown on figure 4.

Installation of air flow regulators in branches, given in table 1, is necessary due to the requirement

for establishment of controlled air distribution in ventilation network. Position of air flow regulators is shown on figure 7. Air flow regulators resistance, pressure drop and opening are given in table 1

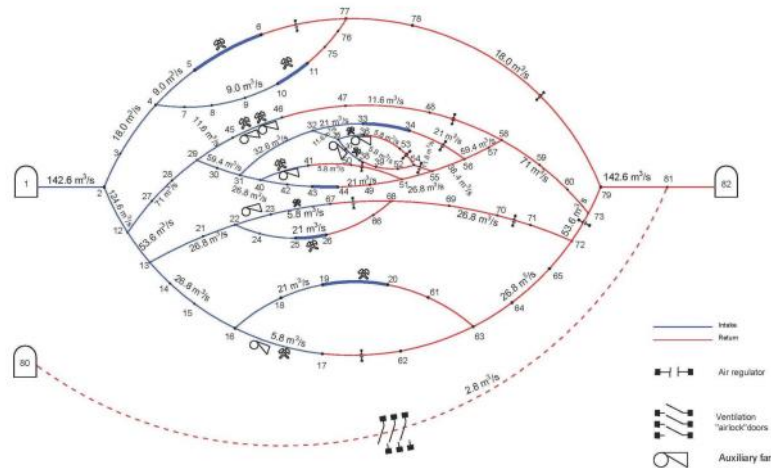


Figure 4 - Canonical ventilation scheme - scenario 1

Table 1. Parameters of mine ventilation regulators - scenario 1

Branch	$R_r(\text{Ns}^2/\text{m}^8)$	$h_r(\text{Pa})$	$A_r(\text{m}^2)$
4 - 5 - 77	0.0169	1.37	7.17
35 - 36 - 54	0.0172	0.58	7.12
35 - 36 - 54	1.7559	59.07	0.87
54 - 55	0.8474	68.64	1.24
34 - 56	0.0955	42.13	3.45
47 - 48	1.8318	246.49	0.86
23 - 67	0.8520	28.66	1.24
17 - 62	1.2892	43.37	1.02
69 - 70	0.0395	28.36	5.07
72 - 73	0.2500	359.12	2.22
78 - 79	2.8137	911.64	0.69

As already mention, installation of main fan in East Decline would establish diagonal ventilation system.

Second analyzed case (scenario 2) is coal production at mechanized longwall panels B20/P3, B33/P3, B19/P1 and B1/P2, with active manual longwalls B19/P2 and B9/P1 and development faces in panels B20/P2, B33/P2 and B1/P1 and roadway development at elevation 127 m and 142 m, with main fan positioned in East Decline (figure 3).

Canonical ventilation scheme of the analyzed mine ventilation - scenario 2 is shown on figure 5. Calculation of ventilation network was performed according to already presented methodology. Results of calculation are shown on figure 5, which also include distribution of air flow within the ventilation network

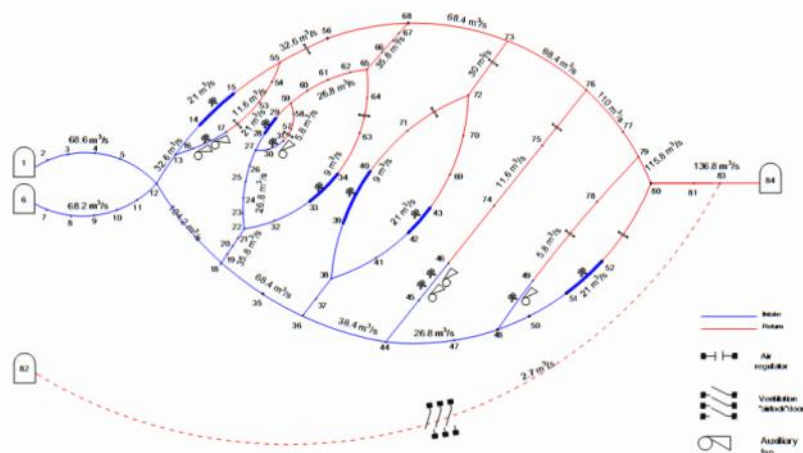


Figure 5 - Canonical ventilation scheme- scenario 2

As in first scenario, installation of air flow regulators is necessary in this case, in order to establish controlled air distribution in ventilation network (figure 5). These regulators, with main parameters (air flow regulators resistance, pressure drop and opening), are listed in table 2.

Table 2 Parameters of mine ventilation regulators - scenario 2

Branch	R_r (Ns ² /m ⁸)	h_r (Pa)	A_r (m ²)
13 - 17 - 55	0.0837	36.91	3.66
27 - 31 - 59	0.9789	32.93	1.16
22 - 65	0.9026	73.11	1.21
55 - 68	0.2454	260.85	2.24
38 - 39 - 72	0.1279	10.36	3.02
72 - 73	0.1168	105.13	3.15
75 - 76	1.4024	188.71	0.98
48 - 79	18.2114	612.63	0.28
48 - 80	0.8984	396.18	1.21

Regarding scenario 1, and based on the aerodynamics resistances and ventilation pressures of roadways, it can be concluded that static ventilation pressure of mine, with given scheme and designed amount of air at level of 145.4 m³/s is $h_{st} = 1843.87$ Pa. In the case of mine ventilation scenario 2, static ventilation pressure of mine is $h_{st} = 1757.05$ Pa with designed amount of air at level of 139.5 m³/s.

Equivalent opening of declines, for both scenarios would be:

$$A_1 = 1.19 \times \frac{Q_{tot}}{\sqrt{h_{st}}} = 1.19 \times \frac{145.4}{\sqrt{1843.87}} = 4.03 \text{ m}^2$$

$$A_2 = 1.19 \times \frac{Q_{tot}}{\sqrt{h_{st}}} = 1.19 \times \frac{139.5}{\sqrt{1757.05}} = 3.96 \text{ m}^2$$

Values of equivalent opening of underground operations, are indicating that these solutions are very favorable for ventilation.

Concept described in this paper has following ventilation network parameters:

Ventilation network parameters	Unit	Scenario 1	Scenario 2
total amount of air	m ³ /s	145.4	139.5
total resistance of the mine ventilation network	Ns ² /m ⁸	0.0872	0.0903
static ventilation pressure	Pa	1843.87	1757.05
equivalent opening of the mine	m ²	4.03	3.96
dynamic ventilation pressure	Pa	529.25	487.35
total ventilation pressure	Pa	2373.12	2244.40
main fan power	kW	431.3	391.4

Main mine fan that can develop static head of 1850 Pa and air capacity of 145.4 m³/s is needed, and it must be able to handle this quantity with high efficiency.

Presented ventilation concepts (scenarios 1 and 2) are in favor of solution with East Decline as main ventilation roadway for exhaust-return air and with main fan installed at entry. Advantage of this solution is improved safety because it has lower total static pressure within ventilation network, which is more favorable in case of coal self-combustion risk. Also, this solution has two roadways for intake air, resulting in better quality of air for ventilation of production and roadway development faces (main coal transport is in one roadway, while the other one is free).

6. CONCLUSION

Case study for the mine ventilation planning and analysis of Derin Sahalar coal mine is presented in this paper. Four mechanized longwalls and two manual longwalls are planned for annual production of

approx. 3.0mtpa of coal in the Derin Sahalar mine. The paper discusses the challenge to coordinate necessary ventilation requirements with long-term demands.

Recommendation of diagonal mine ventilation system is based on the results of the network modeling exercise of the two analyzed options. It is shown that solution with East Decline as main roadway for exhaust-return air and main fan installed at entry (scenario 2) has advantage regarding safety, since it has lower total static pressure in ventilation network. This is preferred situation in case of coal self-combustion risk. Also, this solution has two roadways for fresh air, providing better quality of air for ventilation of faces (main coal transport is in one roadway, while the other one is free).

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REZIME

ANALIZA KONCEPTA VENTILACIJE RUDNIKA UGLJA DERIN SAHALAR

U radu je prikazano konceptualno rešenje ventilacije podzemnog rudnika uglja Derin Sahalar. Rudnik je lociran u centralnom delu Turske (Anadolija) u regionu Kutahia i posluje u okviru turske državne kompanije za proizvodnju uglja (TKI), sa sedištem u Ankari. Planirana proizvodnja rudnika, na godišnjem nivou, iznosi 3,0 miliona t. Ovaj obim proizvodnje, za date ležišne uslove, moguće je ostvari istovremenim radom četiri mehanizovana i dva manuelna širokočelna otkopa. U cilju planiranja i analize ventilacije rudnika, kreiran je ventilacioni model baziran na podacima prikupljenim tokom boravaka u rudniku. S obzirom na planirani vek rada rudnika, poseban izazov je predstavljalo definisanje rešenja ventilacije koje treba da odgovori dugoročnim zahtevima eksploatacije. Shodno rezultatima modeliranja sistema ventilacije, predloženi dijagonalni sistem se nametnuo kao najbolje rešenje. U radu su prikazane prednosti navedenog sistema ventilacije.

Ključne reči: rudarstvo, podzemna eksploatacija uglja, ventilacija rudnika, planiranje sistema ventilacije

Application of an Automated Technique for Topographic Watershed Deriving Using DEM Analysis

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Basic topographic features play major role in deriving basin hydrological characteristics for water resources modeling. Algorithm used in this paper for defining watershed contours relies on digital elevation model (DEM) as primary input data. Accuracy of automatic deriving of watershed contours primarily depends on DEM resolution. On the other hand, accuracy can depend on raster method that is used for stream network delineation into Stream Network raster. To perform this function it is necessary to know how much water flows through each pixel. This means that it is necessary to set the threshold of how many cells flow into each downslope cell to recognize it as a stream. There are several ways to set up the threshold value and herein the calibration method is used. This paper treats Gornja Lisina source, where this method was used to determine watershed contours for 9 springs. Source DEM had 25 m resolution. Various threshold values were tested. For each value catchment area was calculated and compared to area values calculated using common hydrological methods.

Key words: Topographic watershed, DEM, Stream Network raster, Gornja Lisina

1. INTRODUCTION

Automated deriving of hydrological characteristics has advanced lately that much that now it represents integral part of most of the GIS software packages. Automated techniques are faster and may give more precise results than traditional so called manual techniques [1]. Basic requisition for high-quality output is resolution and quality of DEM, which was confirmed by Zhang & Montgomery [2], Wolock & Price [3], Garbrecht & Martz [4], DeBarry [5] and others in their research.

On the other hand, what can have significant effect on quality of calculation is the method itself, because there are various ways of generating DEM.

The accent of the research presented in this paper is on precision of deriving watershed characteristics, i.e. testing of the method of delineation of drainage network into the Stream Network raster.

Previously, Spanish scientists Lopes Garcia & Camarasa [6] have been focused on a very similar topic, so this paper represents sublimation of their work on the data acquired during hydrogeological research campaign for Gornja Lisina groundwater source in 2008-2012.

2. RESEARCH AREA

Geographical Location. Research area is located in SE Serbia, on the territory of Surdulica and Bosilegrad, bordering municipalities with Bulgaria (Figure 1).

Generally, this part of Serbia is sparsely populated, with average of less than one household per km².

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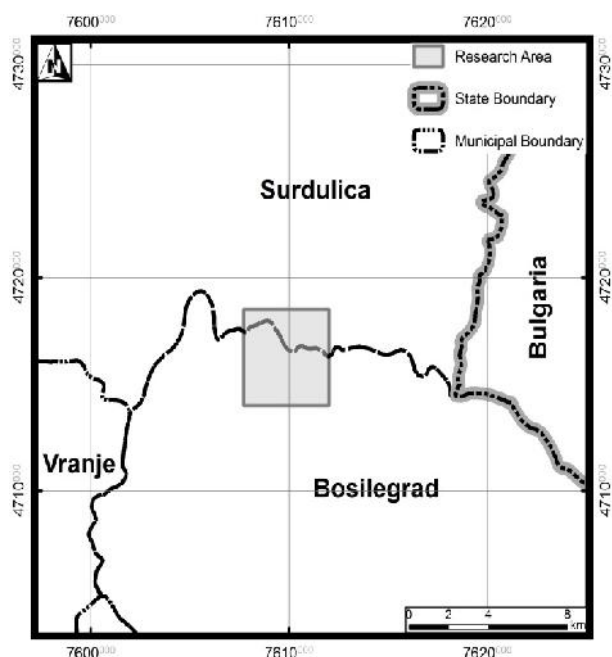


Figure 1 - Geographical location

Geomorphological Setting. Terrain is hilly with mild peaks and clearly expressed gullies. There is significant ground level difference, going from below 1000 m asl in the river valley; up to 1400 m, on locations of several springs; and even higher, on extents of the basin, where elevation goes over 1650 m. Higher zones and peaks are generally dry and uninhabited.

Regarding morphometric characteristics, slope angles in particular, the terrain of the most of the research area (46.67%) can be described as steep, with slope angle 15-25 very steep (26,19%), with slope angle 25-40; and moderately steep (23,00%), with slope angle 7-15.

Geological Setting. There are two dominant geological structures representing the whole area (Figure 2): Božica granitoid body and crystalline schist, while other units are significantly less common.

Božica granitoid is intrusive body that intruded into specific rock formation called Božica series, probably before Devonian [8], causing progressive alteration of the contact part of the series by various processes of granitization and felsparization of schist.

On the extent of the intrusive body, wide aureole of altered schist and gneiss enriched with feldspars and other granitic content was formed, making fine gradation from the intrusive body to the metamorphic complex.

Therefore, on-site distinction of these two formations is very difficult, due to a very similar mineral and chemical composition but slightly different structure [9].

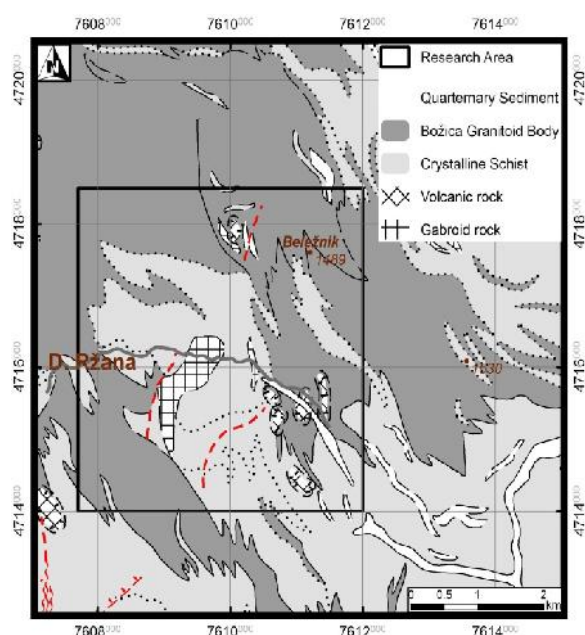


Figure 2 - Geological map

Hydrogeological Setting. Aquifer is formed in shallow fissured environment in the aeration zone i.e. above the local erosive basis. Due to conditions of zones of recharge, groundwater flow and drainage, this aquifer is predisposed to form an open hydrogeological structure [10]. Due to geomorphological, geological and hydrogeological setting, all springs are descending (Figure 3). Aquifer recharges from precipitation directly on the catchment area and because of its elevation (locally higher than 1600 m asl) process of snowmelt plays a significant role in recharge. Groundwater flows through unconfined system of fractures and fissures from recharge zone to the area of descending springs where this aquifer gets drained. Groundwater flow velocity is proportional to the gradient (locally over 0.3) and inversely proportional to the level of infill volume [11].

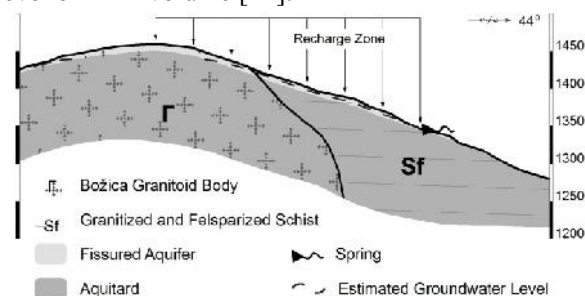


Figure 3 - Typical Hydrogeological cross-section

Source Setting. Groundwater source is located in the catchment area of Lisinska River, cca. 7 km upstream from Gornja Lisina local community. There are nine springs taken into consideration out of which six (#1-6) are positioned on northern and other three (#7-9) on southern side of the catchment area (Figure 4). Each spring is equipped with adequate tapping

construction suitable for monitoring, and therefore suitable for defining of yielding regime. During their construction it was necessary to do additional excavation and cleaning around each spring in order to catch groundwater as efficiently as possible, when it was observed and determined that material was unconsolidated, heterogeneous, with fragments varying from 10 cm to over 1 m, with middle to fine grained matrix.

Having in mind geotechnical classification on: fines, debris and blocks, underlayed by monolith, it can be concluded that these springs have been formed in the zone of debris and blocks. This indicates that the zone of weathering in the drainage area is up to 1 m thick and that the whole aquifer in general is probably only several and not more than 6-7 m thick.

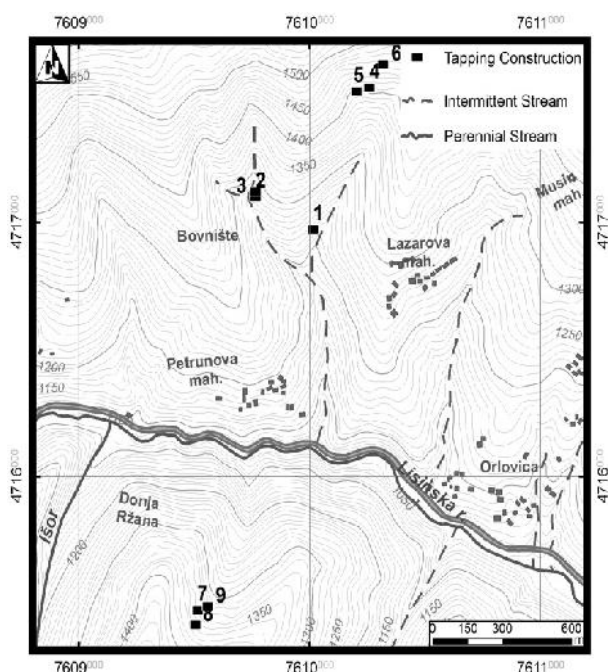


Figure 4 - The source site map

Regarding spatial distribution, i.e. distance between each spring, it is obvious that there are 4 separate sub-watersheds that are getting drained through 9 springs of interest. The first one drains through the spring 1. Second one drains through the springs 2 and 3. Third one drains through 4, 5 and 6 and fourth one through 7, 8 and 9 (Figure 4).

Groundwater yield and temperature regime is under the influence of climatic regime. All springs have relatively low yielding capacity (Tab. 1). Still, the yield is continuous (no drying up along the year), with difference between maximal and minimal value of c. 2.85. Hydraulic conductivity is adopted from empiric values, calculated for granitoid rocks of eastern Serbia [12].

Table 1. Yield and Temperature Properties According to the Monitoring Data Period sep 2008- dec 2009

Spring	Q [l/s]		T [°C]		K [m/s]
	min	max	min	max	
1	0.15	0.34	6.1	7.9	10 ⁻⁶
2	0.14	0.40	6.1	6.9	
3	0.32	0.93	5.9	7.7	
4	0.10	0.14	5.4	8.5	
5	0.08	0.11	6.0	8.2	
6	0.27	0.38	6.2	8.6	
7	0.09	0.12	6.2	8.8	
8	0.07	0.10	6.2	8.1	
9	0.56	0.79	6.3	8.0	

This all unambiguously confirms that the groundwater flow in this shallow aquifer is directly depending on basic topographic features, meaning that groundwater flow modelling can be regarded as hydrological modelling of surface water flow.

3. METHODOLOGY

For automated deriving of hydrological characteristics Hydrology tool of the Spatial Analyst extension of the ArcGIS 9.2 software package was used. In general, when delineating watersheds it is necessary to proceed through a series of steps. Some steps are required, while others are optional depending on the characteristics of the input data. Those used in this paper are marked on general hydrological modelling flowchart (Figure 5).

The first step considered creating of 25 m resolution DEM [13], generated from digitized topo-contours (10 and 5 m equidistance), using Topo to Raster, an interpolation method specifically designed for creation of hydrologically correct DEMs [14], [15]. From this DEM Flow Direction raster (showing the direction of flow-out of each cell) was derived [16], using the according tool. This raster has integrated information on direction vector in each cell i.e. pixel [17] of the research area, which makes it essential for further calculation. Next step considered deriving Sink from Stream Network raster, showing that there was no significant number of sinks. This was „expected“, because naturally occurring sinks in elevation data with a cell size of 10 m or larger are rare, except in glacial or karst areas [18]. Otherwise, sinks would be considered as errors. This means that the main reason for Sink raster deriving was to verify that DEM was hydrologically correctly generated.

Next step was to determine accumulated flow i.e. to derive Flow Accumulation from Flow Direction raster, using the according tool. This tool calculates accumulated flow to each cell, determined by accu-

mulating the weight for all cells that flow into each downslope cell.

According to the flowchart (Figure 5) next step is supposed to be derivation of Stream Link raster i.e. defining every stream channel and junction of the drainage network. However, there is a sub-step of Applying Threshold (Figure 5), which considers prior delineation of stream channels into Stream Network raster. This sub-step in fact represents the essence of this paper. For this purpose, delineation was achieved using Map Algebra tool i.e.

Setnull, sub-tool which sets identified cell locations to NoData based on a specified criterion. In this case, it considered creating a raster where the cell with value 1 represented a stream network on a background of NoData cells. For the processing it was required to “understand” natural processes of the research area in the way to be able to estimate the qu-

antity of water flowing into each cell. This means that in order to create a stream network it was necessary to apply a threshold value to select cells with a high accumulated flow [19], [20]. There are many ways to adjust the threshold value [21] and here a “calibration” was used by applying several different values: 50, 100, 150 and 200. For each applied value delineation of Stream Network was done in order to calculate Stream Link raster. Final step of given flowchart (Figure 5) considered calculation of Watershed raster.

In order to calculate areas of each sub-watershed that is drained through the springs of interest, it was required to make conversion from raster to polygon (vector). Comparatively, sub-watershed areas were calculated using common hydrological methods [22] so the final step was to make comparison between results from both methods (Table 2).

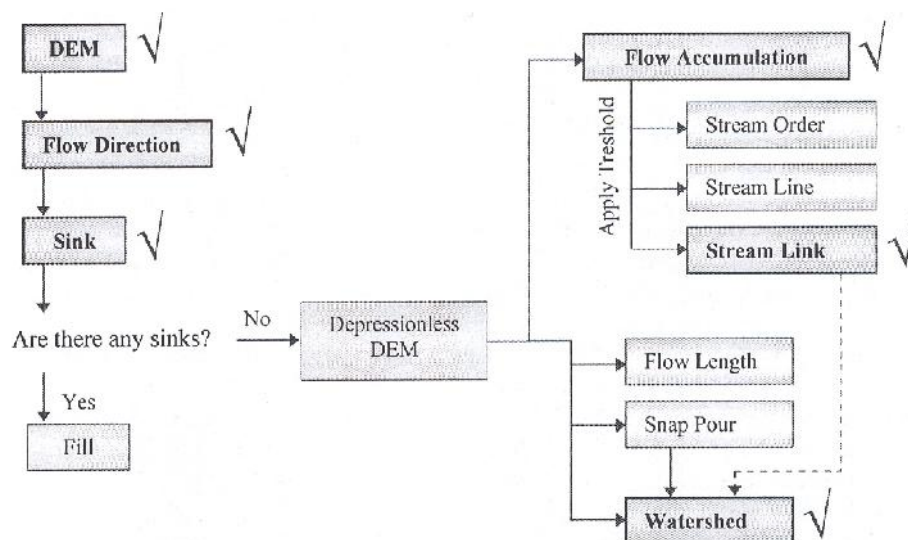


Figure 5 - Hydrological modelling toolset flowchart [23]

4. RESULTS

The fact that has been obvious even before the calculation is that using higher threshold values results in getting lesser cells recognized as the stream and vice versa. Consequently, lesser number of sub-watersheds having greater areas gets identified and vice versa, greater number of sub-watersheds having smaller areas.

Primarily, during analysis of the results in this paper, visual inspection was done. First observation was that applying 200 as threshold value results in obtaining sub-watershed contours not matching realistic natural conditions, since the output result is in fact the whole research area that represents one big watershed draining through all 9 springs of interest. Second observation was that, when applying threshold values 50, 100 and 150, it results in obtaining visually

approximately the same sub-watershed areas extents. Then, values of sub-watershed areas, calculated using common hydrological methods, were compared with values of sub-watershed areas, calculated using each applied threshold (Table 2).

Regarding sub-watershed draining through the spring 1, it is apparent that the results are approximately the same for each method used. For thresholds values 50 and 100, sub-watershed area values are identical and only slightly deviate from values obtained from hydrological budget, while sub-watershed area value for the threshold 150 is slightly lower (Table 2).

Regarding sub-watershed draining through the springs 2 and 3, area value for applied threshold 50 is significantly different from other calculated values, which are approximately the same (Table 2).

Table 2. Sub-watershed Areas -Comparison between Results from Various Methods

Method ↓	Sub-watershed → Deviation[%]	Area [km ²]			
		Spring 1	Springs 2 and 3	Springs 4, 5 and 6	Springs 7, 8 and 9
Hydrological		0.121000	0.324000	0.125000	0.117000
Automated	Streamnet_50	0.122230	0.016228	0.124598	0.112851
	(HL-SN_50)/HL	-1.02	94.99	0.32	3.55
	Streamnet_100	0.122230	0.323071	0.124598	0.117553
	(HL-SN_100)/HL	-1.02	0.29	0.32	-0.47
	Streamnet_150	0.123183	0.335671	0.127339	0.125311
	(HL-SN_150)/HL	9.40	0.12	-1.57	5.04
	Streamnet_200	48.607749			

Regarding sub-watershed draining through the springs 4, 5 and 6, the results are approximately the same for each method used (Table 2). For thresholds 50 and 100, sub-watershed area values are identical, slightly lower than values from hydrological budget, while sub-watershed area value for the threshold 150 is slightly higher (Table 2).

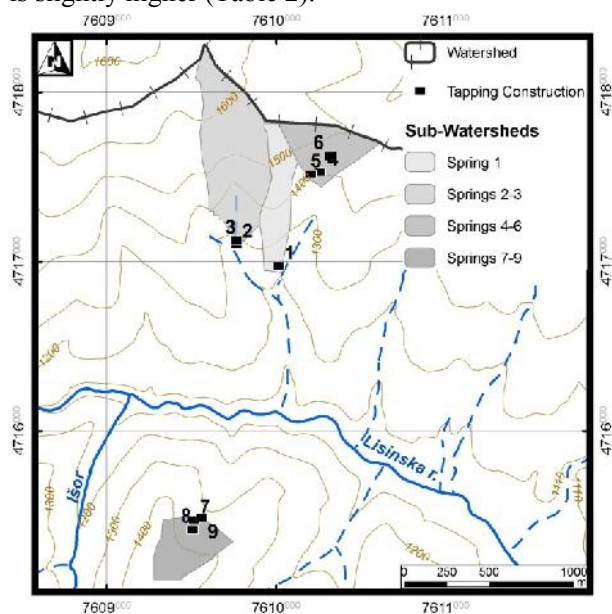


Figure 6 - Position of Sub-watersheds Draining Springs of the Gornja Lisina Source

Regarding sub-watershed draining through the springs 7, 8 and 9, the results are also approximately the same for each method used (Table 2). For thresholds 50 and 150, sub-watershed area values are slightly lower, while the value for threshold 100 is almost equal to the value from hydrological budget, i.e. less than 1% different.

Finally, the conclusion is that, for applied threshold 100, sub-watershed area values are closest to the

values obtained from the hydrological budget and therefore their spatial distribution should be adopted as correct and realistic.

5. DISCUSSION

So far only advantages of this method have been pointed out. However, it is also necessary to discuss its limitations. Latest researches proved that this method was more precise in steeper terrains as a consequence of apparent elevation difference between neighboring cells. On the other hand, application of this method in moderately steep and flat terrains is unreliable, therefore unsuitable [24].

In order to add correction to the calculation, researchers from the Institute for Environment and Sustainability from Varese (Italy) suggested landscape classification, which takes into consideration possibility of drainage density development [25]. The criterion for 5 classes that they offered is: vegetation, climate, terrain morphology, soil type and lithology. In research shown in this paper, this effect was achieved by calibration of Stream Network raster, which considered being well acquainted of terrain properties. However, without that, subjectivity can be brought to the calculation process along with minimizing of analysis effect.

Another limitation can be urbanization and jeopardizing of natural conditions since application of this method is viable only in intact natural conditions.

Finally, eventual fracturing anisotropy in the rock mass and its system of fissures and fractures can limit application of this method. This means that any kind of privileged groundwater flow, which cannot be described as gravitational, cannot be modeled with this method. This method is generally supposed to be used only for hydrological modelling i.e. modelling of surface water flow, but there are exceptions when

it can be applied on groundwater flow as well. That is only when it can be adopted that both ground-and-surface-water flows have same directions, which was the case in the research presented in this paper.

6. CONCLUSION

Automated techniques of deriving hydrological characteristics are fast, precise and relatively simple. DEM is used as basic input so its resolution represents basic variable. For the research presented in this paper 25 m resolution DEM was used and the variable in fact was the method of drainage network delineation into Stream Network raster i.e. the threshold value applied for the calculation. Sub-watershed areas calculated with this method were compared with areas calculated using common hydrological budget methods. Analyzing results for the research area and given 25 m resolution DEM, it is apparent that applying lower threshold values, when deriving Stream Network raster, results in getting bigger number of sub-watersheds with smaller areas and vice versa.

Finally, limitations of this method were presented, where probably the most significant one is that the groundwater flow modeling can be done using this method, but it is only justified when it can be adopted that both ground-and-surface-water flows have same directions.

7. ACKNOWLEDGEMENT

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REZIME

PRIMENA AUTOMATIZOVANE TEHNIKE ODREĐIVANJA TOPOGRAFSKIH VODELNICI ANALIZOM DEM-A

Osnovne topografske osobine igraju važnu ulogu u određivanju hidroloških karakteristika sliva, prilikom modeliranja vodnih resursa. Algoritam, koji je korišćen, u ovom radu, za definisanje kontura vododelnica, se oslanja na digitalni elevacioni model (DEM), kao osnovni rasterski ulazni podatak. Preciznost automatskog načina određivanja kontura vododelnica zavisi, pre svega, od rezolucije DEM-a. Sa druge strane, preciznost može zavisiti i od načina delinacije mreže tokova u raster Stream Network. Da bi se izvela ova funkcija, potrebno je znati koliko vode struji kroz svaki pojedinačni piksel. To znači da je neophodno zadati graničnu vrednost, prag, iz koliko je piksela potrebno da struji voda ka pojedinačnom pikselu, da bi on bio prepoznat kao rečni tok. Taj broj se određuje na različite načine, a na ovom konkretnom primeru utvrđen je tariranjem. Analiza DEM-a je primenjena na Izvorištu u Gornjoj Lisini, gde je za 9 izvora izvršeno određivanje kontura vododelnica, pomenutom metodom. Korišćen je DEM rezolucije 25 m. Za tariranje granične vrednosti broja ćelija, korišćene su različite vrednosti, na osnovu kojih su računane vrednosti površina neposrednih slivova, koje su upoređivane sa vrednostima površina, izračunatim uobičajenim hidrološkim metodama.

Ključne reči: topografska vododelnica, DEM, raster Stream Network, Gornja Lisina

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Use of Finite Element Method in an Assessment of Crack Growth Rate on a Spar of Light Aircraft Under Variable Amplitude Loading

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In the last decades, the assessment of the service durability of aerospace components and assemblies has become an important segment of design. It is especially true for the main structural elements whose sudden failure could lead to the catastrophic consequences. In order to meet the strict safety requirements, a number of expensive and long experiments are carried out. Taking into account manufacturers' tendencies to shorten time-to-market periods, the use of finite element method (FEM) for the assessment of fatigue life has been proved as a good alternative to the experimental methods. The purpose of this paper is to show that it is possible, by using FEM, to obtain good estimation of the fatigue life of the spar assembly, as well as a good prediction of a number of load cycles which will propagate a crack on the spar to a certain length. On the basis of these results, it is possible to determine the proper inspections intervals which could prevent the catastrophic failure of the aircraft structure under variable amplitude loading.

Key words: FEM, crack growth rate, fatigue life estimation, spar of the light aircraft

1. INTRODUCTION

Standard specimens tested under constant amplitude loading have given a number of data on how materials behave under different fatigue conditions [1, 2]. However, during service structural components of aircrafts are subjected mostly to the variable amplitude loading. This means that available fatigue data from tests under constant amplitudes cannot be applied without appropriate modifications. Furthermore, geometry of real component is very often significantly different from the geometry of specimens, which could highly influence the accuracy of fatigue life predictions. In such a case, experimental verification of fatigue life of components (or assemblies) under the variable amplitude loading must be carried out. But, even the smallest change in loading, geometry or materials of components, necessarily leads to new experiments, which makes the design process more expensive.

In a case when numerical model of the structural component or assembly is developed, all required changes are relatively easy to implement. Then, new

estimations of the fatigue life can be obtained quickly and at low costs. However, the question that must be answered is: how can we be sure that the numerical model is good, i.e. that obtained results are reliable and acceptably precise? It is obvious that an initial numerical model must be experimentally verified, and after that the values of fatigue life, obtained by calculations for variable amplitude loading, may be considered as a good enough. Of course, determination of absolutely accurate values is impossible because of probabilistic nature of fatigue failures, i.e. identical components, subjected to the same loading spectrum during the experiment, very often experience large variations in fatigue life. However, numerical methods at least help us to define criteria for acceptance or rejection of the design and also allow Concept A to Concept B comparisons to be made without the need for complete accuracy [3].

2. MATERIAL AND METHOD

The most important roles of the aircraft structures during the life are to transmit and carry loads and provide required lift force (mostly generated by airfoils moving through air). This is achieved by using thin-walled structures in which the interior surfaces are reinforced by longitudinal and transversal strengthening members. A predominant method used for joining all these elements is riveting.

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The wing represents one of the most important assembly zones on aircraft structures which mean that special attention must be paid to determination of the wing fatigue life. The most important element of the wing is I-beam (called spar) which provides stability under compressive loads. It is extended along the length of the wing, in a direction perpendicular to the fuselage. Normally, the wing has 2-3 spars, but light aircrafts mostly have wing with one spar [4]. The spar carries almost all of the bending and shears loads, among of which the lift force is the most dominant. Generated lift force bends the whole wing upright; as a consequence, the upper elements of the spar are under compression, while the lower are under traction.

Spar assembly used in fatigue testing, as well as washers and supportors used to fix spar and apply the load during the experiment, is shown in Figure 1. A critical zone in which, under service loading, the crack most likely to appear, is located in the wing root on the lower side and covers the spar caps and the wing skin. In this case, spar caps and spar web are connected with two rows of rivets of 3.2 mm in diameter. The spar without adjoining skin was tested, so the reinforcing effect of the wing skin was not taken into consideration.

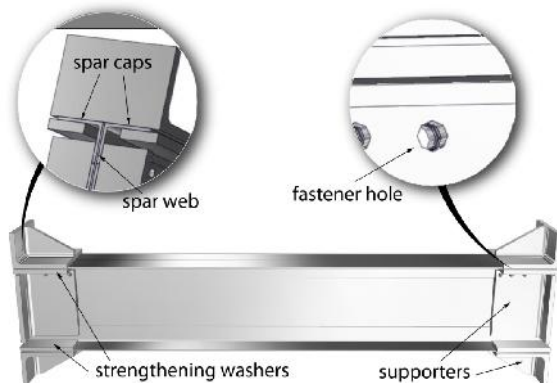


Figure 1 - The spar and supporting elements used in experiment

The spar parts are mainly made of hardened aluminum alloys. The main advantages of aluminum alloys are lightness, high specific strength and good corrosion resistance. The alloys that provide major mechanical properties are Al-Zn-Mg-Cu (the 7xxx family) and Al-Cu-Mg (the 2xxx family). Two mostly used alloys in aerospace applications are 7075-T6 and 2024-T3 [5]. The spar caps in Figure 1 were made from 2024-T3 aluminum plates (thickness 1.6mm), while the spar web was made from the same material, but different thickness (1mm). For the purpose of fatigue testing, ten identical spars have been made. Length of the spars was 600mm which equals the length of constant chord section of the light aircraft.

One of the fundamental issues in the reliability analysis of fatigue behavior of real components under service loading is the evaluation of load or stress spectra. It is a known fact that the nature of the service load is stochastic and that data from original operating conditions are often not available [6, 7]. In recent decades, several standardized load histories have been developed for the purpose of simplification and standardization of fatigue testing procedures. Different load histories have been defined for different types of aircrafts (for example, TWIST and mini-TWIST are used in transport aircrafts testing, FALSTAF and mini-FALSTAF for fighter aircrafts, etc.) Available data may also be used for aircraft types with no defined standardized histories.

2.1 Equipment used in experiments

The increased complexity of the loads history that must be simulated requires development of expensive computer-controlled systems [8]. Much simpler and cheaper system (shown in Figure 2) was developed for the purpose of fatigue testing of light aircraft spar. During the experiment, the force on the drawbar was measured using force transducer of type U3 50kN (Pos.1 in Figure 2). Considering the drawbar to be rigid under predicted external force, deflection of one end of the spar was measured relatively between the spar's end and center point of the drawbar, via potentiometer displacement transducer PM2S 150mm (Pos.2 in Figure 2). Stresses were measured in the clamp area, at 4 points, using aluminum strain gauges of the type 1-LY13-10/120 (Pos.3 in Figure 2). Each strain gauge was connected to one dummy strain gauge (Pos.4 in Figure 2) into one half of Wheatstone bridge circuit, and then with the acquisition system. Data acquisition and analysis were performed using SPIDER8 measurement acquisition system.



Figure 2 - Main components of fatigue testing system used in experiments

Firstly, the spars were tested under constant amplitude loading. On the basis of obtained values, the numerical model was checked. Subsequently, more complex variable amplitude loadings, recommended in literature [9], were applied (loading with lo-hi-lo sequence, randomized block loading, narrow band random loading and broad band random loading). Here, experimental values and FEM simulation results obtained under narrow band random loading (shown in Figure 3) will be presented. The number of loading cycles in this sequence was 157.

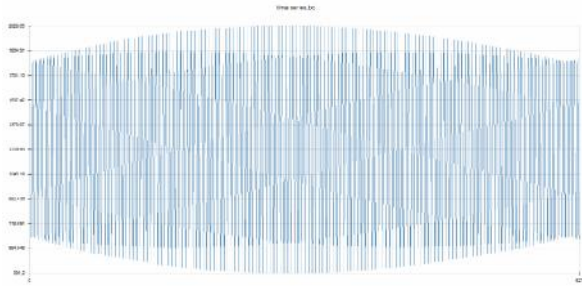


Figure 3 - Narrow band random loading used in experiment and FEA

2.2 Verification of numerical model

Initial finite element model of the light aircraft spar (Figure 4), including supporters and washers, was developed in the Ansys Workbench software [10]. Final model, used in the calculations, had 2410012 nodes and 1224900 finite elements, and was obtained by means of iteration process which consisted of comparison of numerical values obtained for current mesh against the values obtained in tests under constant amplitude loadings (four spars were used for that purpose).

In each step of the iteration process, mesh was improved in order to get numerical solutions closer to the experimental values. Fatigue life was calculated using stress-life (S-N) method, because the number of cycles to visible damage in experiments was over 3×10^6 for all four spars. When fatigue life of the spar, obtained by finite element analysis, was finally very close to the mean value of experimental results, numerical model was accepted as a satisfactory. Tests of the spar under variable amplitude loading started immediately after that; narrow band random loading, was one of the load histories used in tests.

Load history shown in Figure 3, (minimal value +391.2N, maximum value +2028.0N, frequency 12.5 Hz), produced strong tension stress in upper caps, so visible crack appeared on the left cap below supporter, after only 8542 cycles (Figure 5). The crack began to spread rapidly towards the spar web, then changed its direction and continued to propagate along the cap at an angle of 90° with respect to the

original direction. Simultaneously, it moved towards the left edge of the cap.

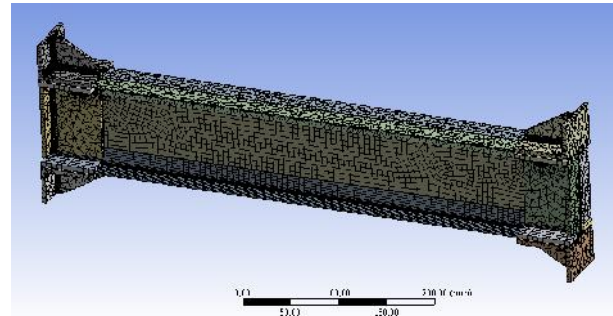


Figure 4 - Initial finite element mesh

In order to carefully study the crack propagation, testing was paused at intervals, some inspections were performed and current length of crack was recorded. After 39450 cycles, another crack was spotted on the right spar cap, for which later was determined to have occurred on the fastener hole (Figure 6). The crack was spotted when it moved to the area between horizontal and vertical wall of the cap, because it occurred below the upper supporter and initiation wasn't registered visually.



Figure 5 - Location of the first crack initiation

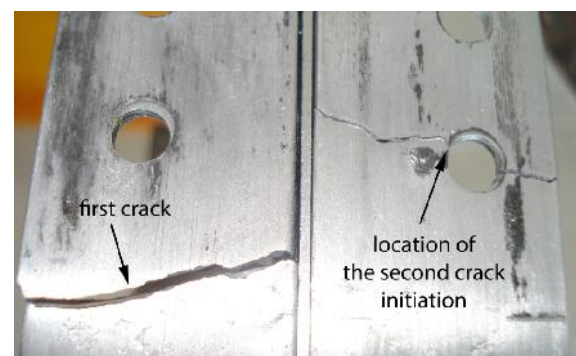


Figure 6 - Locations and paths of cracks on horizontal walls of the spar caps

Cracks then continued to propagate below the strengthening washers and were not visible anymore, so after 58520 cycles the test was stopped and the

spar was examined in order to determine what was going on below the strengthening washers. Then it was noticed that both cracks came to the side fastener hole, i.e. to the last holes on both upper caps (Figures 7 and 8).

It was also found that the crack didn't initiate on the spar web and at the moment when the experiment was stopped, nothing indicated that the final failure of the spar would come soon. Aside from the cracks on the caps, there were no signs on any other damage of the spar assembly.



Figure 7 - First crack growth path

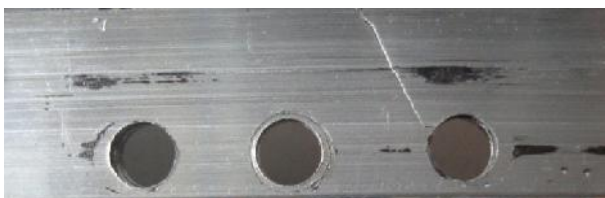


Figure 8 - Second crack growth path

After the experiment a FEM calculation was performed in order to determine if the numerical model in Ansys, under identical loading history like a real spar, shall give an approximate value of the fatigue life. Taking into account that the first crack appeared after only 8542 cycles (which is obviously an example of low cycle fatigue) the ϵ -N method (strain life method) was used in the calculation, with the spectrum (Figure 3) being loaded from Spider into Ansys.

Since during the experiment both the variable amplitude load and displacements were measured, calculations in Ansys were performed not only with the variable force acting at the end of the spar, but also with applied displacement at the end of the spar. Fatigue life values obtained in both cases were slightly different - 50.6 blocks in the case of applied force (Figure 9) and 52.6 blocks for applied displacement.

Considering that one block consists of 157 cycles, it is easy to calculate that FEA in Ansys predicts that the crack on the spar will appear after approximately 7944 cycles. In Figure 9, it is clear that Ansys predicts initiation of the fatigue crack near the location where it was seen in the experiment, confirming that the numerical model was well defined.

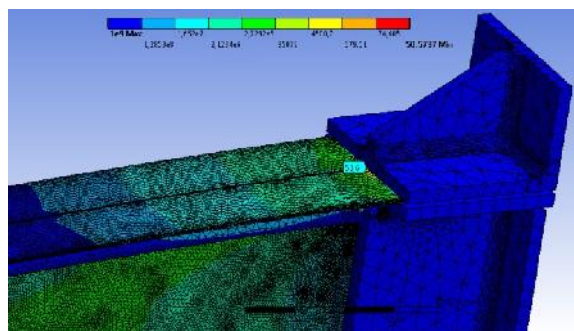


Figure 9 - Values of fatigue life (number of blocks of spectrum) obtained in Ansys

2.3 Numerical model used in crack propagation simulation

After having obtained approximately the same number of the cycles to initial damage, a new numerical model was defined, for the purpose of performing crack growth simulation in both upper spar caps. Considering that both cracks moved firstly along horizontal walls of the caps and then along vertical walls (being connected to spar web by rivets), it was concluded that the crack growth should be simulated from the moments they started to propagate along vertical walls towards side fastener holes. It was estimated that this was the critical phase of growth for both cracks. Simulation of crack growth on horizontal wall was not challenging because of only one layer of material under loading. On the other hand, analysis of the crack growth on vertical walls includes a definition of three layers of materials with different thicknesses (two caps and web) and simulation of riveted joints. Since thickness of caps is 1.6mm and thickness of the web is 1mm, this can be considered as the through crack case and numerical modeling of crack propagation in a 2D aluminum plate should provide good results. Numerical modeling of through crack was performed in the software for 2D crack analysis FRANC2D/L [11].

FRANC2D/L is an interactive program for the crack growth simulations in multi-layered structures and provides representation of lap joints or bonded repairs. Each layer must be represented by a separate mesh that, in the zone of overlapping, must be identical to the mesh of other layers and which is connected to them with rivet or adhesive elements. Aside from that, all layers must be flat and both two-dimensional and three-dimensional calculations can be performed. However, for complex 3D models it's better to use FRANC3D software specialized for three-dimensional problems [12].

Figure 10 shows a part of generated mesh of the first and third layer (thickness 1.6 mm) around fastener holes on the vertical walls of upper spar caps.

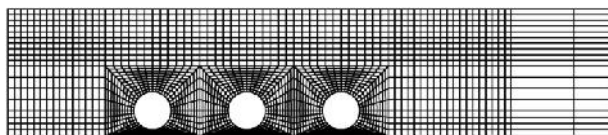


Figure 10 - Finite element mesh around fastener holes on upper spar caps (1st and 3rd layer)

The second layer represents the spar web (thickness 1 mm) and it is placed between the first and third layer. The mesh of all three layers was made in the CASCA program [11], and the layers were connected by rivet elements. In the FRANC2D/L program, the rivets are considered as elastic shear springs where the rivet stiffness is the constant of material (rivet stiffness can be determined by approximate formula $K_{\text{rivet}} = 12EI/7L^3$ [13]).

Rivets may only be introduced at nodes and when they connect two layers, they must be defined at a node in the upper layer. It must be underlined that the lower spar caps were not modeled in order to reduce the number of finite elements used in the calculations.

After the layers had been connected, displacements of nodes on left edges of all three layers were fixed in both directions, as well as displacements of nodes at upper and lower edges in the clamp area. Then, 3 mm displacement in vertical direction (maximum displacement in experiment) was applied on all nodes of the right edge of the second layer (spar web).

Deformed meshes of all three layers (shown in Figure 11) were the proof that rivet elements successfully transferred the loading from layer 2 to layers 1 and 3. Values of stresses obtained in FRANC2D/L were close to the values obtained in Ansys.

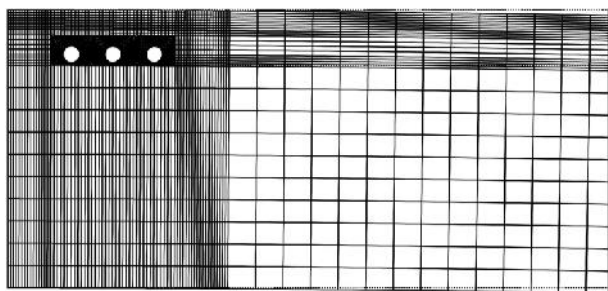


Figure 11 - Deformed meshes of all three layers

Since in FRANC2D/L user can choose between two types of cracks, internal and edge crack, it was decided to initiate both cracks on the upper edges of the first and third layer and to propagate them towards fastener holes. To determine exact positions for cracks initiation, Figure 7 and 8 were used. Initial position of the crack on the first layer is shown in Figure 12 whereas the position of the second crack is shown in Figure 13.

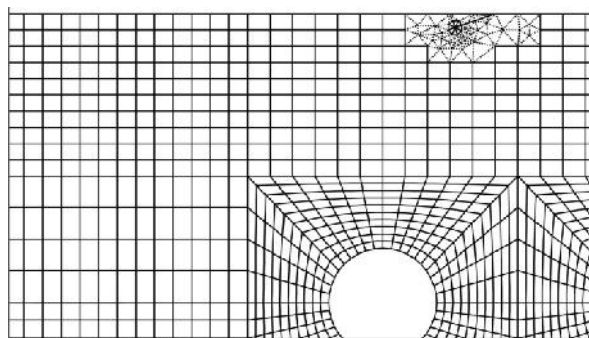


Figure 12 - Initial position of the first crack

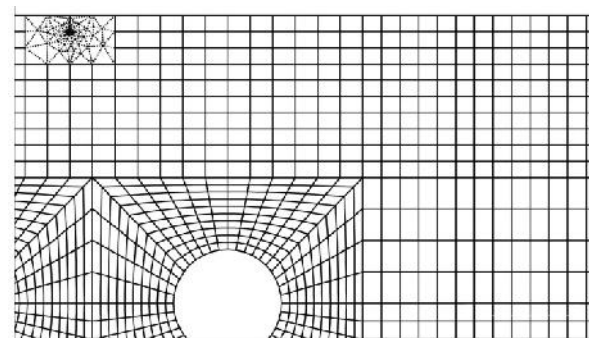


Figure 13 - Initial position of the second crack

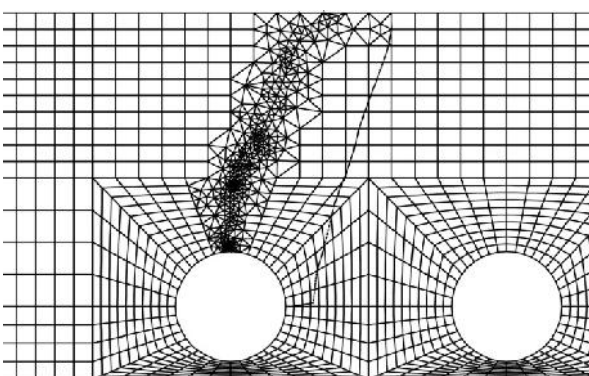


Figure 14 - First layer mesh after crack growth (dashed line represents second crack path)

The cracks were propagated using standard method that predicts direction of propagation according to maximum hoop stress in the vicinity of the crack tip [14].

Each time cracks were propagated the mesh was modified in order to reflect the current crack configuration and values of stress intensity factors were calculated using the displacement correlation method or modified crack closure techniques [14].

The cracks were propagated simultaneously and after nine steps of propagation they came to the edges of fastener holes (Figures 14 and 15). It can be seen that paths obtained in finite element simulation were similar to those observed in experiment with variable amplitude loading shown in Figure 3.

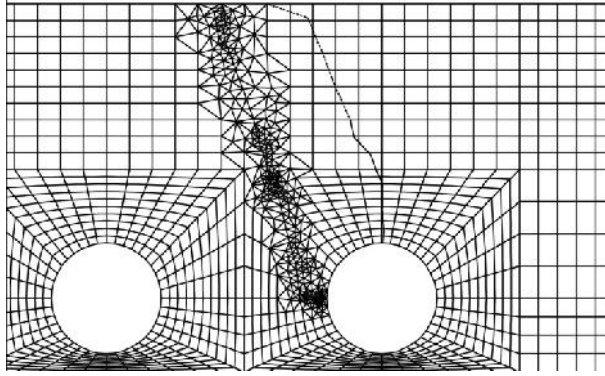


Figure 15 - Second layer mesh after crack growth (dashed line represents first crack path)

3. CRACK PROPAGATION SIMULATION RESULTS

The stress intensity factors (SIFs) values, obtained in FRANC2D/L and saved in a text file, were used as input to FRANC2D/L Crack Growth Program (F2D/LCG) [11] that permits the calculation of the crack growth curve. Other inputs for F2D/LCG are Time History File (loading spectrum) and Material File (mechanical and fatigue properties of 2024-T3 aluminum alloy).

Spectrum is counted by F2DL/CG with a Range-pair algorithm [15], and the crack growth curve is calculated by integrating modified Forman-Mettu NASGRO equation for fatigue crack growth rate (da/dN) expressed as a function of crack-tip stress intensity factor range ΔK [16]:

$$\frac{da}{dN} = C \left[\left(\frac{1-f}{1-R} \right) \Delta K \right]^n \frac{\left(1 - \frac{\Delta K_{th}}{\Delta K} \right)^p}{\left(1 - \frac{\Delta K_{max}}{\Delta K_{crit}} \right)^q} \quad (1)$$

In Equation (1) C , n , p and q are the material parameters, f denotes the crack opening function, whereas R -ratio of the load is defined as $R=R_{min}/R_{max}$ (or $R=K_{min}/K_{max}$). F2D/LCG has set of files providing NASGRO equation coefficients for aluminum alloys [17], and after selecting 2024-T3 aluminum (thickness 1.6mm) da/dN plot may be seen.

The thickness of material t is one of the independent parameters entering in the NASGRO equation and it affects the critical SIF (ΔK_{crit}) according to the Equation (2)

$$\frac{\Delta K_{crit}}{K_{IC}} = 1 + B_K \cdot e^{-\left(\frac{A_K t}{t_g} \right)} \quad (2)$$

where K_{IC} , A_K and B_K are material parameters, while t_o is given by the following equation (in plane strain conditions):

$$t_o = 2.5 \cdot \left(\frac{K_{IC}}{\sigma_{ys}} \right) \quad (3)$$

By default, the Mode I SIF (K_I) is used for integration of Eq. 1, so ΔK is obtained according to the formula $\Delta K = K_{I_{max}} - K_{I_{min}}$. However, integration on the basis of K_I values gave the fatigue life $N=124492$ cycles for the first crack. This value is almost three times as big as the value obtained in the experiment. For second crack calculated fatigue life was $N=14001$ cycles. Analysis of the SIF history file showed that the values of stress intensity factors Mode II (K_{II}) were not negligible for the first crack. On the basis of this finding it was determined to use K_{eff} in calculation, given by Equation (4):

$$K_{eff} = \sqrt{K_I^2 + \beta \cdot K_{II}^2} \quad (4)$$

where β is material property. Therefore the ΔK used in Eq. 1 is $\Delta K = K_{eff_{max}} - K_{eff_{min}}$.

Instead of K_I , K_{eff} was used for integration of Eq. 1 and results showed that the number of cycles required for first crack to grow up to $a=14.92\text{cm}$ was $N=40413$ (i.e. 257.4 blocks of spectrum shown in Fig. 3) and that the number of cycles required for second crack to grow up to $a=13.26\text{cm}$ was $N=13392$ (i.e. 85.3 blocks) (Figure 16). Calculated fatigue life values are similar to values obtained in the experiment which justifies the use of K_{eff} in calculation. It is especially truth for the first crack, whereas the difference in number of cycles obtained for K_I and K_{eff} in the case of the second crack is very small (14001 versus 13392 cycles). This indicates the negligible influence of K_{II} on the second crack growth rate.

Finally, the crack growth curve calculation was performed for standard spectra mini-TWIST and mini-FALSTAFF [18] in order to obtain the estimation of the number of cycles required for cracks to grow up to dimensions obtained in the experiment. The calculation in Ansys under mini-TWIST spectrum showed a damage appearance after approximately 660000 cycles and under mini-FALSTAFF spectrum after 290000 cycles. Figure 17 shows the fatigue life $N=1849468$ cycles (or approximately 103 flight hours) obtained for the first crack under the mini-TWIST spectrum loading, as well as the fatigue life $N=1072496$ cycles (or approximately 60 flight hours)

for the same crack under the mini-FALSTAFF spectrum.

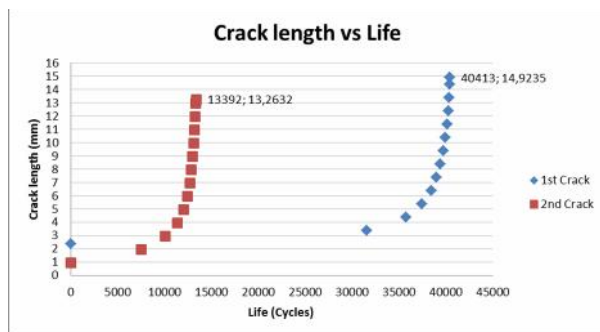


Figure 16 - Crack length vs. Life for both cracks

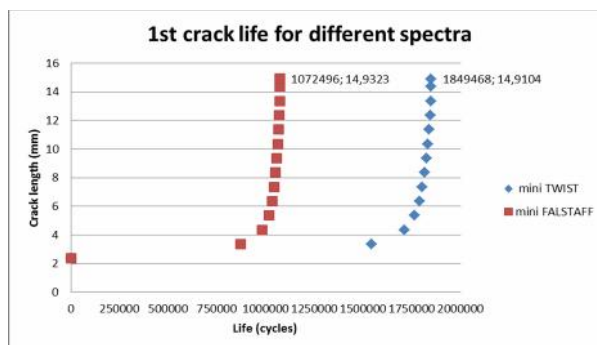


Figure 17 - First crack length vs. Life under different spectra

In Figure 18 obtained values of fatigue life for the second crack can be seen: under mini-TWIST spectrum $N=389350$ cycles (or 22 flight hours) and under mini-FALSTAFF spectrum $N=257220$ (or 14 flight hours).

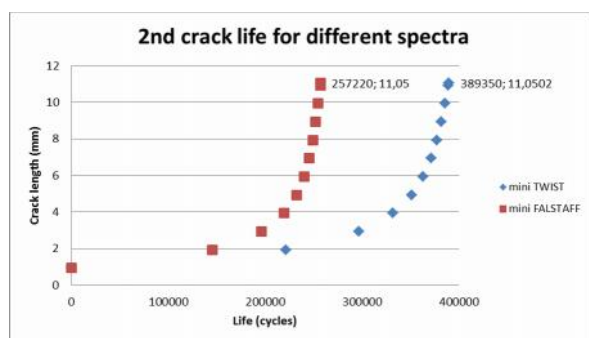


Figure 18 - Second crack length vs. Life under different spectra

4. CONCLUSIONS

Comparing the values obtained in the experiment against those obtained by numerical simulation, similarity of results is obvious. In the experiment, the first crack appeared after 8542 cycles and FEA predicted damage appearance under variable amplitude load not earlier than 7944 cycles. Adding this value to the number of cycles $N=40413$ required to move first crack on the left spar cap wall towards the last fa-

stener hole, we get total fatigue life $N=48357$. In the experiment, first crack came to the last fastener hole after 58520 cycles. Difference of approximately 10.000 cycles may be explained by the fact that before crack moved from horizontal to vertical wall of the spar cap, it had propagated for a while through the area between the vertical and horizontal wall.

The second crack was seen later in the experiment (after 39.450 cycles), at the moment when it became visible in the area between horizontal and vertical wall. It was found that this crack initiated from the fastener hole below upper supporter and this initiation may be explained by the stress concentration around a circular hole. Unfortunately, exact number of cycles required to initiate the second crack wasn't recorded. Adding calculated number of cycles ($N=13392$) required to move second crack on the right spar cap wall towards the fastener hole to the number of cycles to visible crack in the experiment, we get total fatigue life $N=52.842$ for the second crack. As previously suggested, the difference of approximately 6000 cycles can be explained by crack propagation in the area between the walls.

Values of fatigue life under mini-TWIST and mini-FALSTAFF loading spectra were relatively low, but it must be noticed that these are standard spectra used in transport and fighter aircrafts fatigue tests, not in light aircraft tests. However, the light aircraft service load history is in some way similar to the transport aircraft load history. Values of fatigue life under mini-TWIST spectrum obtained by numerical simulation are between several hundred thousand cycles (second crack) and several million cycles (first crack). In practice, when aircraft inspection intervals must be determined, these values can be considered as reliable.

Finally, the entire process of the crack growth simulation by means of finite element method has proved successful and reliable because calculated values matched the results of experiment. Of course, it mustn't be forgotten that fatigue has stochastic nature and that the same spar under the same loading may show different fatigue behavior, i.e. the crack may occur sooner or later and on other locations, too. However, numerical models presented in this paper may still be used for new crack growth simulations and estimations of the residual life of the light aircraft spar under variable amplitude loading.

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REZIME

METODA KONAČNIH ELEMENATA U PROCENI BRZINE RASTA PRSLINE NA RAMENJAČI LAKOG AVIONA IZLOŽENOJ OPTEREĆENJU PROMENLJIVE AMPLITUDE

Dobra procena zamorne izdržljivosti vazduhoplovnih komponenti i sklopova je poslednjih decenija postala važan segment projektovanja. To se posebno odnosi na glavne strukturne elemente kao što su ramenjača krila, glavni okvir trupa i okovi, čiji bi eventualni lom usled zamora mogao da dovede do katastrofalnih posledica. Da bi se ispunili strogi zahtevi po pitanju bezbednosti, sprovode se brojna eksperimentalna ispitivanja koja su često skupa i dugotrajna. S obzirom na stalno prisutnu težnju proizvođača da vreme između idejnog projekta i gotovog proizvoda smanje na najmanju moguću meru, korišćenje metode konačnih elemenata (MKE) u proceni zamornog veka se pokazalo kao dobra alternativa eksperimentalnim ispitivanjima. Namena ovog rada je da pokaže da je korišćenjem MKE moguće doći ne samo do dobre procene ukupnog zamornog veka sklopa kao što je ramenjača lakog aviona, već da je moguće predvideti i broj ciklusa opterećenja koji će dovesti do stvaranja prsline određene dužine na ramenjači. Na osnovu rezultata ovakvih proračuna mogu se odrediti intervali preventivnih inspekcija koje bi predupredile nastanak katastrofalnog loma.

Ključne reči: MKE, brzina rasta prsline, procena zamornog veka, ramenjača lakog aviona

Fluid Structure Interaction on the Example of Real Artery Bifurcation of Random Selected Patient

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This paper presents the procedures and tools developed for simulating the fluid and structure interaction on the example of a patient-specific carotid artery bifurcation. Volumetric model of the carotid artery bifurcation is obtained through the processing of images from CT scanner. Finite-element model, generated using multiblock approach, accurately reflect the arbitrarily shaped domain. Presented numerical results show that developed methodology is very flexible and efficient for the applied research in biomedical engineering. Thanks to the detailed image about the phenomenon that occurs when blood flows through the carotid artery bifurcation, cardiologists make a decision on the necessity of intervention.

Key words: *fluid-structure interaction, blood flow, FEM, wall shear stress, artery bifurcation*

1. INTRODUCTION

Fluid-structure interaction problems are too complex to be solved analytically [1, 2]. Therefore, these problems are analyzed experimentally and by numerical simulations [3, 4]. Over the years, mathematical modeling, such as the finite element method (FEM), has become a complementary to experimental approaches in the study of clinical problems, as well as predicting the biomechanical behavior [5-7]. The finite element method allows the reiteration of numerical experiments by changing certain parameters. In this way researchers are able to analyze the impact of specific variables on the observed phenomenon [3].

The finite element method requires the existence of the physical domain in which the problem is observed

and discretization of the domain. Accurate capturing of the geometry of the blood vessel does not guarantee accurate modeling. The generation of high-quality mesh of eight-noded 3D finite elements for complex structures is still a significant problem [8]. The existing methods are also very slow. It is well known that the quality of the mesh plays a significant role in the simulation using the finite element method [9]. The accuracy of the numerical solution depends on the type of finite elements used in modeling of the physical domain. Numerical errors are dependent on the quality of the mesh, which is especially important in computational fluid dynamics, where the numerical errors become visible in the resulting solution.

Research in computational fluid dynamics and solid mechanics are still in focus of many scientists and research institutions. The computational fluid dynamics is used in biomedicine in order to achieve better understanding of how fluid flows in arteries and veins. Blood flow is governed by the Navier-Stokes eq-

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uations and the continuity equation. Computational solid mechanics is used to calculate the corresponding stress and strain of arterial walls, using specially developed material models [10].

Numerical simulation of interaction between solids and fluids belongs to the group of coupled multiphysics problems, which in this decade has been the subject of intense research and development of simulation codes [10]. Starting from models that describe each domain individually, defined system of equations is describing the coupled behavior of these two domains [10-12]. During the calculation of coupled problems fields of pressure, velocity and shear stress on the arterial wall are determined for fluid domain, while the stresses and displacements at the nodes are determined for solid domain.

This paper presents a methodology developed for the rapid modeling of the blood and blood vessels interaction on the example of the complex geometry of real arterial bifurcation.

2. PAK-FS – COMPUTER CODE FOR SIMULATION OF FLUID STRUCTURE INTERACTION

Two basic approaches for numerical solution of the fluid-structure interaction are strong coupling and weak coupling [10, 12]. The basic idea of the strong coupling is to solve complete system of equations in one step. In this way, all variables, related to solid and fluid, are determined simultaneously. This methodology becomes enormously expensive to solve 3D problems, which dramatically increases system of equations to be solved. In order to solve the coupled problems using this methodology, it is necessary to make a specific solver for solving solids and fluids. An alternative method to strong coupling is the weak coupling, which has a number of advantages. The main advantage is the use of an already existing program to solve solids and fluids with very small modification. Calculating the unknown values for the solid and fluid are independent, in separate programs, where the variables at the interface are exchanged at each time step.

For the numerical simulation of the fluid-structure interaction problem software PAK-FS [13] is used, developed by coupling existing software for computational fluid dynamics PAK-F and software for computational solid dynamics PAK-S, using the weak coupling. The calculation results are written to the file FEMAP Neutral, IDEAS UNV and the VTK. The global algorithm of developed code is shown in Figure 1.

Fluid and structure occupies different subdomains, and the corresponding system of equations is set

independently for each subdomain, providing that the subdomains discretizations are compatible on the interface.

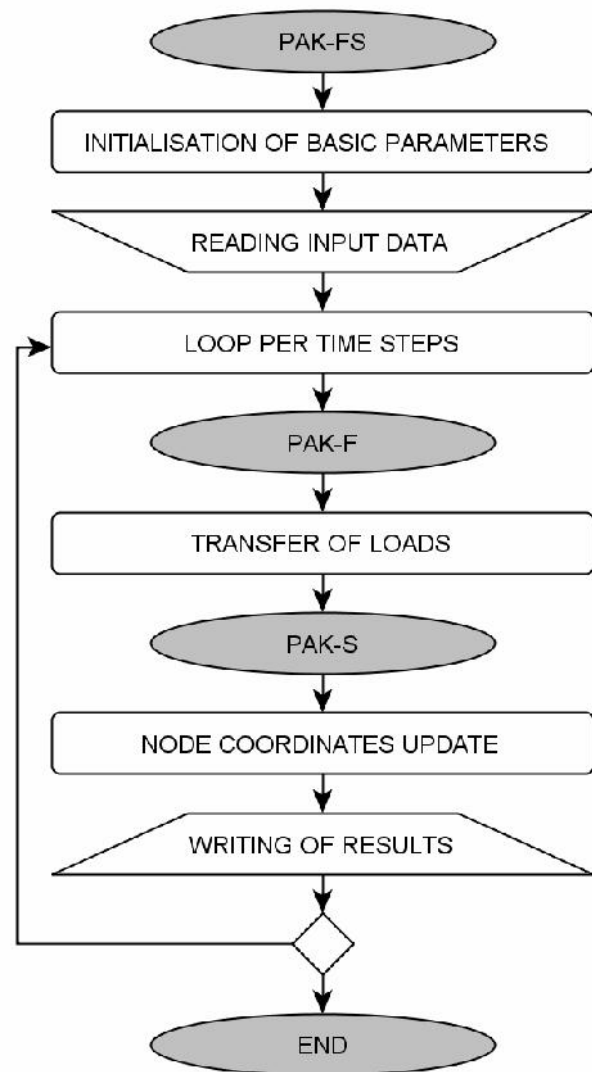


Figure 1 - The global algorithm of PAK-FS

Program for Computational Fluid Dynamics (CFD) as a boundary conditions uses the current geometry (surface) and the velocities of the nodes corresponding to these surfaces. This information was obtained by computational solid dynamics program that solves problems in the domain of solids (arterial wall). On the other hand, the load of the domain of the fluid is transferred into a solid domain.

3. METHODOLOGY FOR RAPID FINITE ELEMENT MODEL GENERATION OF ARTERIAL BIFURCATION

Bifurcation sites of human arteries are among the most frequent locations affected by atherosclerosis, being involved in up to 20% of percutaneous interventions. Several studies on the distribution of plaque

in the cardiovascular system have shown that atherosclerosis occurs mainly on the branches of the vascular tree, where the arteries have relatively complex geometry [14-16]. The complex geometry conditions affect the flow, which is unique for each individual patient [14]. Most flow simulations reported in literature were conducted over the so-called average or idealized geometries. The solutions thus obtained may significantly deviate from the solutions to obtain some accurate modeling of blood vessels [17]. Nowadays, the trend and the need are to generate models that accurately describe the actual geometry of arterial bifurcations due to improvements made in the fields of equipment for radiological diagnostics and computer performance [18-19].

Contribution of authors to improve the methodology of generating high-quality finite element mesh is described in detail in this section. To speed up the process of generating models, software STL2BLOCK is developed. Based on volumetric models obtained by radiological imaging it generates a topology of the blocks for generating finite elements by multiblock method. The first step in generating a finite element mesh is the determination of the geometry of the wall of carotid artery. It is now possible to do this in many ways, such as computed tomography (CT), magnetic resonance imaging (MRI)... The original CT images, which contain information about the tissues in the vicinity of the branch of the carotid artery using DICOM format are loaded into the software MIMICS. In this software, for each of the images, based on adjustable thresholds contrasts, regions representing different tissues and organs of the observed image are identified. By merging the boundaries of these regions, along with the information about the spatial position of each image, and then by polygonization of models, the 3D model of all organs whose contrast corresponding to the selected range is generated. Figure 2 shows the volumetric models of tissue, mainly the bone and blood vessels, which are obtained by treating the images generated by computer tomography (CT scanner).

From this set we should exclude all but blood flow organs (Figure 3). Imperfections of software for the volumetric model reconstruction cause that this model include plaque built of calcium, creating the illusion that the flow cross-section is increased. The reason for this is that calcium has the same contrast ratio as the blood, and the software does not distinguish these two materials. These places need to be fixed by deleting the local irregularities in polygonized mesh and reconstructing the resulting discontinuities. If necessary, decimation of model can be performed to the level of the retention of the necessary quality of details, which affects the performance

of the next steps in the FEM model generation process. Finite elements mesh generation starts from the point that the exact geometry of the models is contained in the STL file, the interface to the next stage in the model's creation.



Figure 2 – Volumetric model of tissue (blood and bones) generated by processing of CT images

Structured mesh is most appropriate method for domain discretisation. Method is founded on direct mapping from physical to computational model (Figure 4a). Points at domain border are used for interpolation of points inside computational domain. Structured mesh provide finite element mesh that accurately describe the boundaries of the domain, so the boundary conditions are accurately and correctly set for the given domain. The application of structural mesh is limited to domain with simple geometry. Modeling of complex domains is difficult or impossible to the procedure described above.

Instead, the authors propose a composite or multiblock approach in which the computational domain is divided into a finite number of smaller domains called blocks [20-21]. The entire mesh is formed by connecting these blocks. Each block in the physical domain is mapped to a polygon block in the data domain (Figure 4b). Structural mesh techniques are now applied to the individual blocks, which can then be joined together by building a complex mesh that

accurately describe the complex geometry of diseased and/or normal blood vessels.

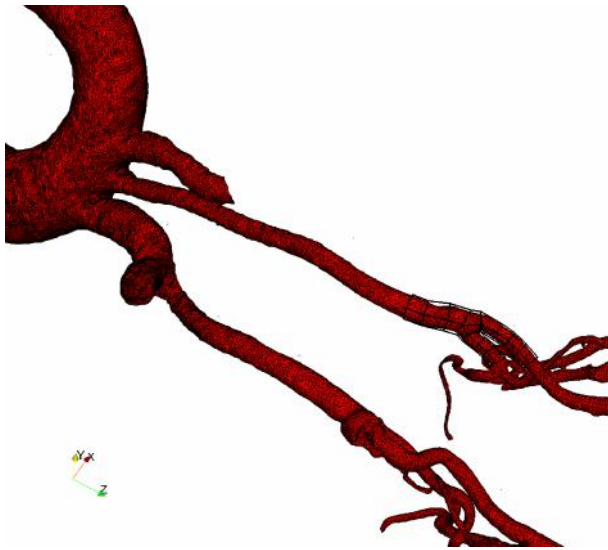


Figure 3 – Volumetric model of carotid arteries tissue

Blocks are represented using hexahedron, defined by vertices and edges. Local nodes labeling of blocks is shown in Figure 4a. The distribution of points within a block is determined by solving a set of three Poisson equations, one for each local direction of the block.

The software Geomagic Studio is used for setting the planes that define sections in which the vertices of blocks will be placed. Planes are placed so that they are aligned perpendicularly to the centerline of the blood vessel in the chosen field. The three planes are required to define a set of observed domain boundaries. Other planes are placed in areas where there is a change of direction, or bending of the vessel. The software reads the data on the cross sections from the file, and then specifies the center of gravity for section. To determine the center of gravity for section it is necessary first to set up a central intersection point whose coordinates are the average of the coordinates of all points of intersection. Further procedure is reduced to the determination of center of gravity for complex surface, consisting of triangles with vertices at the center point and the intersection point along the line of intersection. For each cross-section is determined the maximum dimension of intersection and normal vector to the intersection.

External vertices of blocks are placed so that they are aligned in cross section and are in the middle of the maximum dimension of intersection of the center of gravity of section in the directions of the local coordinate axes x_1 and y_1 (Figure 4b). Internal vertices of blocks are placed by the same criteria as outside, except that half of the maximum dimensions section is multiplied by a user-defined positive factor of pro-

portionality. This factor is in the interval $[0, 1]$ and is defined in a configuration file. Vertices of the blocks are numbered with 1-8, where number 1 carries the lower left vertices on the inside, and the number 5 carries lower left vertices on the outer ring. The vertex following the numbering of the sections has a larger to 8 in relation to the vertex of which precede them.

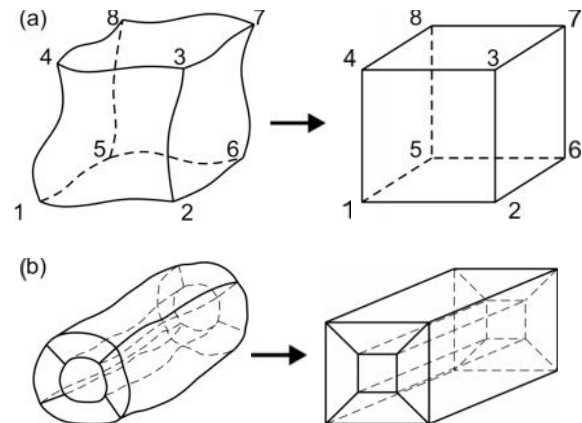


Figure 4 - Block – Basic tool in multiblock concept of finite element mesh generation

Different topologies of blocks can be applied to the vertices set. The blocks are labeled in such a way that the central block is a 1, the blocks 2, 3, 4 and 5 below, to the right, above and to the left of the central unit, respectively. This layout of blocks is seen from the top of the local z axis. Adding a new section the total number of blocks increases by 5. Applied block structure is favorable for all sections, because all of the observed branches have the same arrangement of the blocks, as can be achieved with any other configuration. Figure 5 shows the blocks generated by software STL2BLOCK.

The left and right carotid bifurcations for a particular patient are not geometrically identical. On the basis of practical examples, it is well known that the geometry of the bifurcation is very different for different patients. In rare cases manual intervention is required to fine-tune the vertices of the blocks to cover the bifurcation itself as accurately as possible.

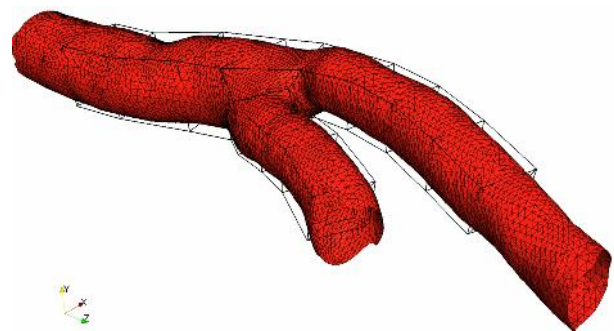


Figure 5 – Blocks generated using software STL2-BLOCK

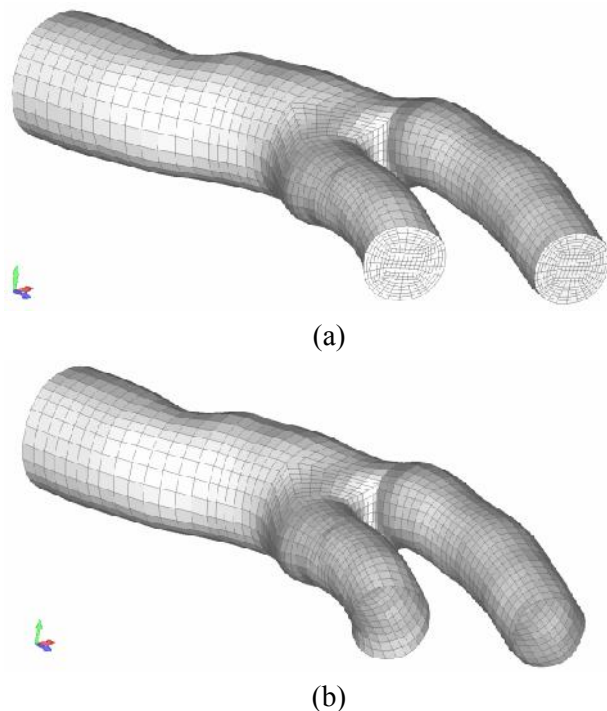


Figure 6 – Finite element models of carotid artery bifurcation: (a) fluid domain i (b) solid domain

Topology of blocks is recorded in the VTK file, and can be used in other software for generating 3D finite element mesh. An example of such software is IA-FEMesh [22], open source software that relies on VTK library. The software uses the multiblock method for generating finite elements, wherein the nodes are generated using the transfinite interpolation without relaxation of the mesh [23]. You can create two types of finite elements: eight-noded 3D elements (Figure 6a) and four-noded shell elements (Figure 6b). The resulting finite element models accurately reflect the observed physical domain.

4. NUMERICAL SIMULATION OF FLUID-STRUCTURE INTERACTION

Simulation of blood flow through an elastic blood vessel was carried out on the example of real artery bifurcation of random selected patient whose model is shown above. The calculation was performed using the software PAK-FS.

The calculation was performed in 30 time steps in the interval of 0.8s. The first 10 steps are at intervals of 0.02s, and other 20 steps are at intervals of 0.03s. We used the following input data for the fluid domain: the average flow velocity at the inlet section $v_{SR} = 16.9 \text{ cm/s}$, density of blood $\rho = 1050 \text{ kg/m}^3$ and

coefficient of dynamic viscosity $\mu = 0.003675 \text{ Pa} \cdot \text{s}$ [24-25]. The input data for the elastic artery wall are: modulus of elasticity $E = 0.361 \text{ MPa}$, Poisson's coefficient $\nu = 0.49$ and density of the arterial wall tissue $\rho = 1100 \text{ kg/m}^3$. In the simulation standard systole and diastole phase of an adult human cardiac cycle is used (Figure 7) [25].

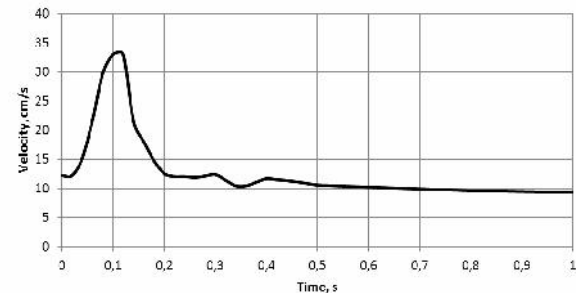


Figure 7 – Velocity field in the centroid of the input section for one cardiac cycle

For the fluid domain the following boundary conditions are applied:

- parabolic velocity profile corresponding to the developed laminar flow through a straight circular pipe is set on inlet section,
- the deformability of the arterial walls, and the speed of the interface equal to the velocity obtained from the calculation of strength are taken into account, and
- at the outlet sections of the model there is resistance that occurs because the flow of blood continues through the other blood organs.

For solid domain nodes at the inlet section have constrained movement in the flow direction. Also, movement of the section centroid is limited to the plane of the input section.

In the following figures the results of interaction of fluid and solid simulation are shown. Velocity field in the third step of the cardiac cycle is shown in Figure 8a.

When pressures on the model outlet surfaces are not given as boundary conditions, the result is the field of pressure drop in the modeled domain. Field of the pressure drop in the third step of the cardiac cycle is shown in Figure 8b. Field of endothelial shear stress on the blood vessel walls in the third step of the cardiac cycle is shown in Figure 9a. Places with lower stress value are more prone to plaque occurrence, so this result is of great importance in the diagnosis and treatment of atherosclerosis. Field of the equivalent

stress of the arterial walls in the third step is given in Figure 9b.

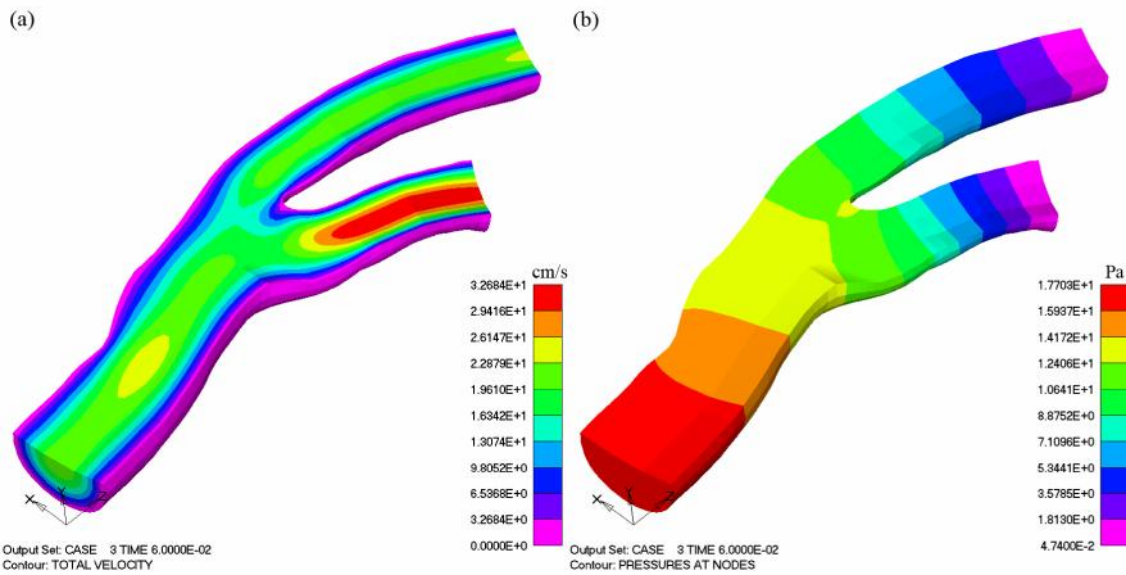


Figure 8 – Velocity field (a) and Field of pressure drop (b) in 3rd step of cardiac cycle

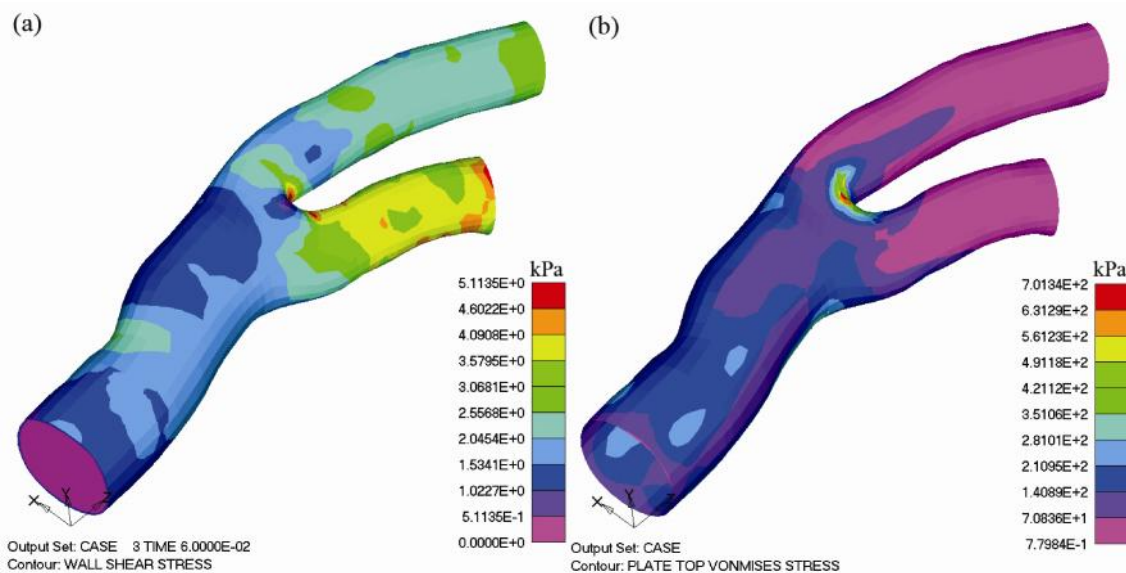


Figure 9 – Endothelial shear stress (a) and Equivalent stress (b) in 3rd step of cardiac cycle

5. CONCLUSION

Developing of new software for solving problems of interaction between solids and fluids is a difficult and time-consuming task.

When the softwares to solve fluid and solid dynamics separately already exist, cost-effective solution is to write drivers to use these solvers with minor modifications. To this end, as better solution is implementation of the weak coupling of these solvers, because in that case each solver solves part of the problem in the domain for which is designed. However, this coupling is due to its specificity, which normally does not occur in the strong coupling, prone to many problems. The primary problem is the time integra-

tion. Because of the diversity of the physical characteristics of solids and fluids, it is generally not possible to use the same time step. Another difficulty arises in solvers communication. Different (incompatible) discretization is additional problem because it is necessary to transfer data from one mesh to another.

The proposed solution covers the entire process of analysis by software developed at the Faculty of Engineering, University of Kragujevac (STL2BLOCK - software for generating blocks for the discretization of the domain and the PAK FS - software for solving the coupled problem of fluid dynamics and the dynamics of solids) and open source software (IA-FEMesh - software for generating finite element meshes, and PARAVIEW - software for post-proce-

ssing of the results). The methodology has been applied to the real model of arterial vascular bifurcation of the patient, taking into account the elastic wall of the blood vessel. The presented methodology is applicable to modeling other branches of the flow-organs of the human body (coronary artery branching, branching in the lungs, ...).

When generating finite element mesh multiblock approach was used, which speeds up the process of generating multiple models while minimizing errors in the numerical solution. The developed tool is very effective in creating computational meshes for the complex geometry in biomechanics and engineering in general. In this way, hardware demanding and time-consuming procedures of NURBS surface reconstruction, and then the CAD modeling are skipped, because the finite element model is created directly on the volumetric model.

The presented results show that the deformation which occurs at the interaction between the blood and the arterial wall significantly affects the values of the hemodynamic forces acting on the arterial wall, as compared to the case when rigid wall is observed. Compared to previous studies [17] it was observed that simulations carried out with negligence of the arterial wall elasticity overestimate the maximum value of shear stress, and its field distribution on the arterial wall.

Based on the obtained results it can be concluded that this methodology is a useful tool that can provide important baseline information to cardiologists. Thanks to the detailed image of a phenomenon which occurs when blood flows through the carotid artery bifurcation, they decide whether and at what time point some intervention is required.

ACKNOWLEDGEMENTS

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REZIME

INTERAKCIJA SOLIDA I FLUIDA NA PRIMERU REALNE GEOMETRIJE ARTERIJSKE BIFURKACIJE SLUČAJNO IZABRANOG PACIJENTA

U radu su prezentovane razvijene procedure i alati za simulaciju interakcije fluida i strukture na primeru realne geometrije karotidne arterijske bifurkacije slučajno odabranog pacijenta. Geometrija karotidne arterijske bifurkacije dobijena je obradom snimaka sa CT skenera. Model konačnih elemenata verno opisuje složenu geometriju domena. Prikazani numerički rezultati pokazuju da je razvijena metodologija veoma fleksibilna i efikasna za primenjenu istraživanja u biomedicinskom inženjeringu. Zahvaljujući jasnoj predstavi o fenomenima koji se javljaju pri strujanju krvi kroz bifurkacije karotidne arterije, kardiolozi donose odluku o neophodnosti intervencije.

Ključne reči: interakcija fluida i strukture, proticanje krvi, metoda konačnih elemenata, napon smicanja na zidu, arterijska bifurkacija

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Novel Realization of Bandstop Waveguide Filters

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This paper presents different models of bandstop waveguide filters using split-ring resonators. Novel microstrip resonators are proposed and they are applied as printed-circuit inserts in the transverse planes of the waveguide. These resonators are designed as single-mode and dual-mode. The filter response is analyzed in terms of various parameters of the resonators, including their position. Considered waveguide filters are designed using various structures of the printed-circuit inserts with split-ring resonators in order to obtain single-mode and dual-mode bandstop filter response. A novel filter design procedure is developed, which provides the possibility to realize multi-mode bandstop waveguide filters, and dual-mode filters introduced here represent the examples of their practical implementation.

Key words: split-ring resonator, bandstop waveguide filter

1. INTRODUCTION

Bandstop filters are used to suppress spurious signals and higher harmonics within the systems designed to operate in RF, microwave and millimeter-wave frequency ranges [1]. Waveguide filters have significant role when it is necessary to implement high power structures with small losses. Their principle of operation is based on the insertion of the discontinuities, acting as resonators, inside the waveguide [2]. Split-ring resonators (SRRs) have wide implementation for filter design, and they also represent sustainable solution for bandstop waveguide filter (BSWF) realization. They can be employed to operate as single-mode or dual-mode resonators. Dual-mode resonators can be developed from the single-mode resonators. The important characteristic of this type of resonators is that their two operating modes do not couple with each other [3]. Based on that, filter using SRRs can be realized to cover two frequency bands, providing compact structure and decreasing the total cost of the device.

In this paper, various models of the BSWFs, operating in X-band and realized using microstrip single-mode and dual-mode SRRs, are presented. Thereby, dual-mode resonators are designed starting from the single-mode resonators, and the position of these SRRs is chosen in such a way that the coupling effect is eliminated, thus each one of them can be independently controlled. The considered resonators are then implemented as printed-circuit inserts in the transverse planes of the rectangular waveguide, in order to obtain waveguide filters. By choosing the proper position of the SRRs, first-order single-mode and dual-mode bandstop filters are realized, followed by single-mode third-order filters, and finally dual-mode third-order filter is realized as an example of multi-mode bandstop waveguide filter design. For the design and analysis of the considered structures, WIPL-D software [4] is used.

The objective of this research is to develop and design novel SRRs, to model BSWFs using these resonators and to analyze filter responses depending on various parameters of these SRRs, including their mutual position. Dual-mode bandstop filters are realized using different implementations of the SRRs, in order to be able to compare filter responses and to evaluate considered solutions. The proposed design provides the possibility to develop multi-mode band-

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stop filters, and here are presented dual-mode first-order and third-order bandstop filters, as examples of its practical application.

2. BANDSTOP WAVEGUIDE FILTERS USING SPLIT-RING RESONATORS

The filter design and analysis start from the model of the BSWF, with central frequency of 11.95 GHz. The similar model of the bandstop filter, though with different central frequency, was proposed in [1], [5]. Three-dimensional (3D) electromagnetic (EM) model of the filter using one SRR is shown in Figure 1.

For the filter design, the standard WR90 rectangular waveguide of width $a=22.86$ mm and height $b=10.16$ mm is used. It is assumed that the dominant mode of propagation is the transverse electric TE_{10} mode.

The waveguide filter is excited by quarter-wave monopole, modeled as a thin wire with an ideal voltage source at the position where the wire is connected to the waveguide wall. Each septum presented in the paper is realized as a printed-circuit insert using RT/Duroid 5880 ($\epsilon_r=2.2$) board with thickness of $h=0.8$ mm and metallization thickness of $t=0.018$ mm.

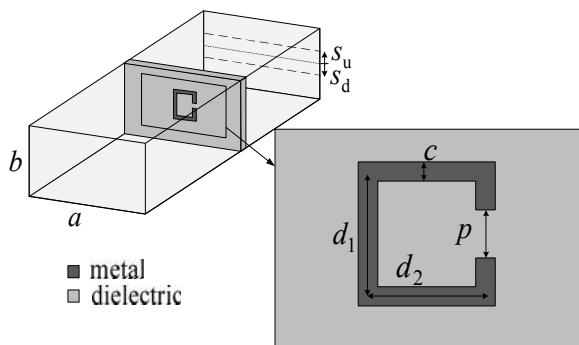


Figure 1 - 3D EM model of the BSWF using one SRR (type I)

In order to optimize the operation of the resonator, its parameters are tuned by means of WIPL-D simulations. According to the labels in Figure 1, for the model of the filter with resonant frequency of $f_0=11.95$ GHz, the SRR with the following dimensions is used: $d_1=2.5$ mm, $d_2=3.1$ mm, $c=0.2$ mm, $p=0.9$ mm.

First, the influence of the resonator position (on the insert) on the filter response is analyzed. Namely, the resonator is moved up and down, related to the central position and the filter responses are compared. These results are given in Figure 2 for the case when the resonator is moved up and down for $s_u=s_d=2.85$ mm, related to the central position.

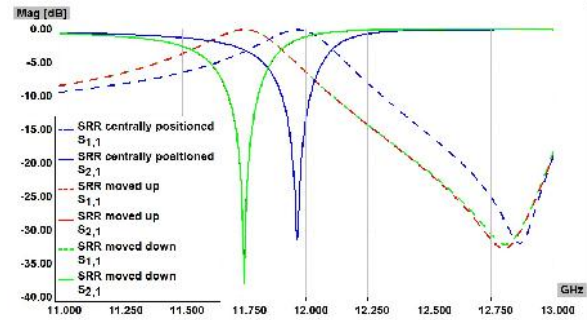


Figure 2 – The resonant frequency variation with position of the SRR given in Figure 1

The influence of the parameters of the SRR on the resonant frequency and bandwidth are investigated by means of simulations in WIPL-D software and the filter responses are compared. The obtained simulation results are given in Table 1.

According to these results, it can be noticed that the variation of the resonator length, for the given width and size of the gap, moves the resonant frequency position: by increasing the length of the SRR, the resonant frequency moves toward the lower values, but the bandwidth is not significantly affected. On the other hand, the variation of the width, for the chosen length of the SRR and size of the gap, primarily introduces the change of the bandwidth.

Table 1. The influence of the SRR parameters (Figure 1) on the resonant frequency and bandwidth

$d_1=2.5$ mm, $c=0.2$ mm, $p=0.9$ mm			$d_1=2.5$ mm, $d_2=3.1$ mm, $p=0.9$ mm		
d_2 [mm]	f_0 [GHz]	B_{3dB} [GHz]	c [mm]	f_0 [GHz]	B_{3dB} [GHz]
4.8	9.020	0.373	0.2	11.966	0.368
3.6	10.929	0.383	0.4	12.056	0.430
3.1	11.966	0.368	0.8	12.314	0.546

The second model of the insert is realized using dielectric plate which covers a half of the waveguide transverse cross-section and it is connected to the side walls of the waveguide. 3D EM model of the filter with the SRR realized in this manner is depicted in Figure 3.

According to the labels in this figure, for the BSWF model, with resonant frequency of $f_0=9$ GHz, dimensions of the SRR are: $d_1=2.5$ mm, $d_2=4.9$ mm, $c=0.2$ mm, $p=0.9$ mm. The dimensions of the dielectric plate are $a_{pl}=10.16$ mm and $b_{pl}=5.08$ mm. The plate has central position in the transverse cross-section of the waveguide, and the SRR is also centrally positioned on the plate. WIPL-D model of this filter is shown in Figure 4.

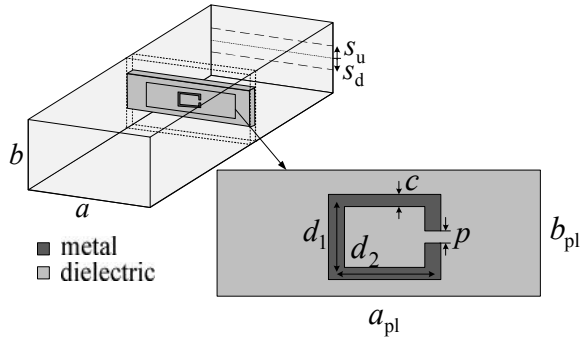


Figure 3 - 3D EM model of the BSWF using one SRR (type 2)

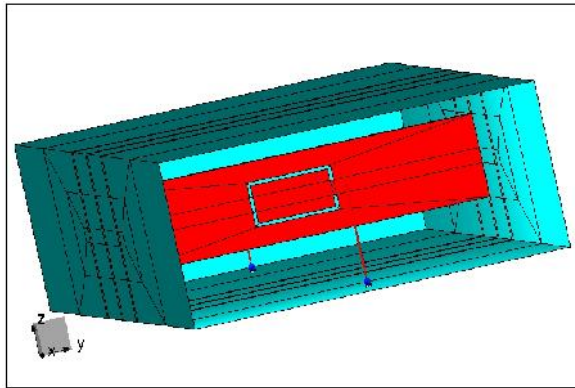


Figure 4 - WIPL-D model of the BSWF using one SRR (type 2)

The influence of the position of the plate with SRR on the filter response is investigated. Namely, the plate is moved up and down related to the central position and the filter responses are compared. These results are given in Figure 5 for the case when the resonator is moved up and down for $s_u=s_d=2.1$ mm, related to the central position.

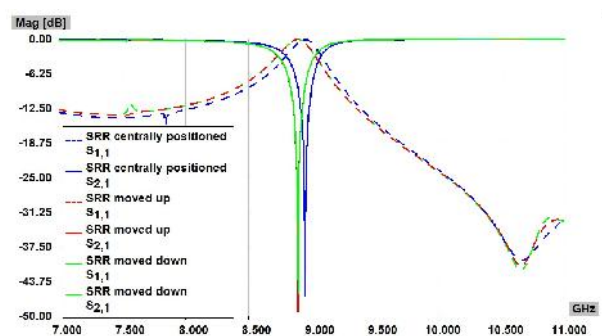


Figure 5 – The resonant frequency variation with position of the SRR given in Figure 3

The third model of the insert is realized using dielectric plate whose size is significantly smaller than dimensions of the transverse cross-section of the waveguide. The plate is connected to the upper and the lower waveguide wall using thin dielectric strips. 3D EM model of the filter with the SRR realized in this manner is depicted in Figure 6.

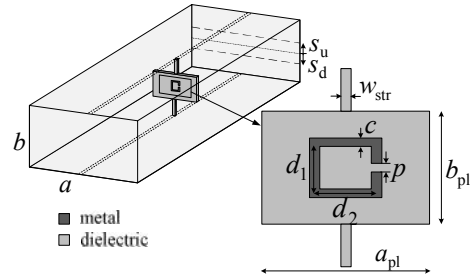


Figure 6 - 3D EM model of the BSWF using one SRR (type 3)

The BSWF, with the resonant frequency of $f_0=9$ GHz, is realized using these inserts. According to the labels given in Figure 6, parameters of the SRR are: $d_1=2.5$ mm, $d_2=4.9$ mm, $c=0.2$ mm, $p=0.9$ mm. The insert is modeled as dielectric plate of width $a_{pl}=7$ mm and height $b_{pl}=4$ mm, connected to the upper and the lower waveguide wall using dielectric strips of width $w_{str}=0.4$ mm. WIPL-D model of this filter is shown in Figure 7.

As for the two previous cases, the influence of the plate position on the filter response is also analyzed for this insert model. Namely, the plate is moved up and down, related to the central position, and the filter responses are compared. These results are given in Figure 8 for the case when the resonator is moved up and down for $s_u=s_d=2.85$ mm, related to the central position.

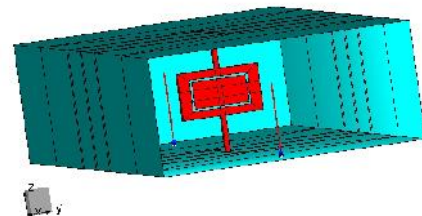


Figure 7 - WIPL-D model of the BSWF using one SRR (type 3)

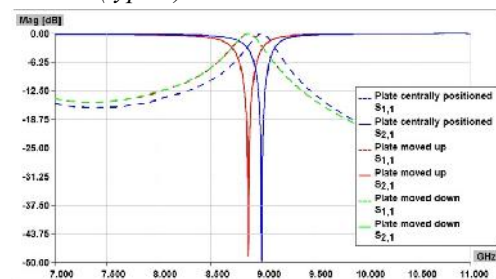


Figure 8 – The resonant frequency variation with position of the SRR given in Figure 6

For the filter realized using these inserts, the influence of the SRR parameters on the filter response is also investigated and the obtained results are given in Table 2. It can be concluded that the resonant frequency moves toward higher values as the resonator

length decreases. According to the filter response behavior for various widths of the resonator, it can be noticed that this parameter primarily influences the bandwidth, while the frequency shift is relatively small.

Table 2. The influence of the SRR parameters (Figure 6) on the resonant frequency and bandwidth

$d_1=2.5$ mm, $c=0.2$ mm, $p=0.9$ mm			$d_1=2.5$ mm, $d_2=4.9$ mm, $p=0.9$ mm		
d_2 [mm]	f_0 [GHz]	B_{3dB} [GHz]	c [mm]	f_0 [GHz]	B_{3dB} [GHz]
4.90	8.995	0.266	0.1	8.936	0.235
4.20	9.995	0.272	0.2	8.995	0.266
3.60	11.059	0.288	0.3	9.043	0.293
3.15	12.000	0.285	0.4	9.091	0.325

The obtained results for the filter response variation with SRR position show that, for the chosen resonator length, the resonant frequency of the BSWF can be tuned by moving the resonator up and down, and thereby there is not significant change in the bandwidth. This analysis aims to investigate the mutual coupling of the resonators realized on the same plate, within the same transverse cross-section of the waveguide. To be more precise, the separation of the resonators is considered in order to achieve negligible mutual coupling and this is important for the multi-mode filter design.

For each presented type of the insert, it can be noticed that, by moving the resonator up and down, related to the central position, some change of the resonant frequency is also introduced. Thus it is necessary to slightly modify dimensions of the SRR in order to achieve required resonant frequency for the chosen position.

Finally, the responses of the filters realized using proposed inserts (type 1, 2, 3) are compared. For the example of the filter with resonant frequency of 9 GHz, using SRR centrally positioned in the transverse plane, the results are shown in Figure 9. It can be concluded that the results are matched relatively good in terms of resonant frequency and bandwidth, but the return loss has the lowest values beyond the stop band when the filter is realized using the insert marked as type 3.

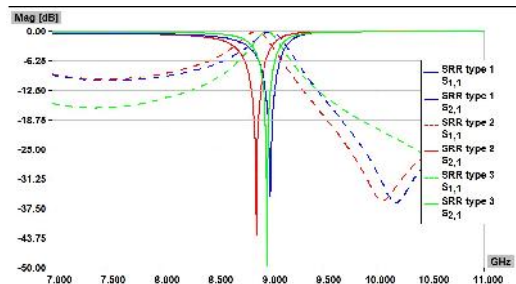


Figure 9 – Comparison of frequency responses of the BSWFs using proposed SRRs (type 1, 2, 3) 3. dual-mode bandstop waveguide filters

3. DUAL-MODE BANDSTOP WAVEGUIDE FILTERS

Single-mode SRRs, presented in the previous section, are used for the design of the dual-mode resonators. The mutual distance between the resonators is chosen in such a way that the coupling effect is practically eliminated, thus their resonant frequencies can be independently controlled. These SRRs are then implemented as printed-circuit inserts in the rectangular waveguide, in order to obtain dual-mode BSWF. Here, models with resonant frequencies of $f_{01}=9$ GHz and $f_{02}=11$ GHz are considered.

The first model of the dual-mode BSWF is realized using insert across the entire transverse cross-section of the waveguide, with two SRRs of type 1 for different resonant frequencies. In this manner, dual-mode resonator is obtained, and by employing this resonator, dual-mode BSWF is realized. 3D EM model of this filter is depicted in Figure 10. According to the labels given in this figure, dimensions of the SRRs are given in Table 3. WIPL-D model of the filter is shown in Figure 11. The distance between the SRRs is chosen in such a way that their mutual coupling is eliminated, so the resonant frequencies can be independently tuned. In the considered example, this distance is set to $r=3.5$ mm.

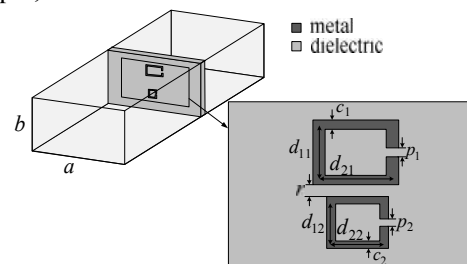


Figure 10 - 3D EM model of the dual-mode BSWF (model 1)

Table 3. Dimensions of the SRRs given in Figure 10

Resonant frequency	d_{1i} [mm]	d_{2i} [mm]	c_i [mm]	p_i [mm]
$f_0 = 9$ GHz ($i = 1$)	2.5	4.7	0.2	0.9
$f_0 = 11$ GHz ($i = 2$)	2.5	3.4	0.2	0.9

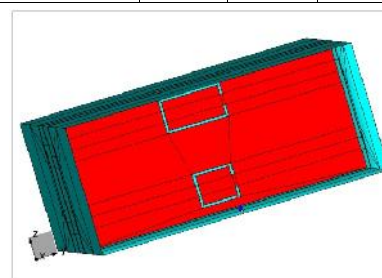


Figure 11 - WIPL-D model of the dual-mode BSWF (model 1)

The second model of the dual-mode BSWF is made using two inserts across the entire cross-section, each of which contains one SRR of type 1. The po-

sitions of the SRRs on the inserts correspond to their positions when they are both realized on the same insert (model 1), in case when their mutual distance is set to $r=3.5\text{ mm}$. Thereby, the inserts are separated by the distance of $(\lambda_{g9\text{GHz}} - \lambda_{g11\text{GHz}})/4 = 3.68\text{ mm}$ [6]. 3D EM model of this filter is shown in Figure 12. Dimensions of the SRRs are the same as for the previous model (Table 3).

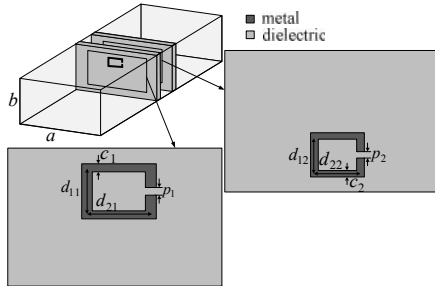


Figure 12 - 3D EM model of the dual-mode BSWF (model 2)

The third model of the dual-mode BSWF is realized using inserts across one half of the waveguide cross-section and they are connected to its side walls (SRRs of type 2). The distance between the inserts is the same as in the previous case (model 2), and the positions of the SRRs in the transverse planes correspond to those used in the previous model. Dimensions of the SRRs for this case are also given in Table 3, and dimensions of the plates are $a_{pl}=10.16\text{ mm}$ and $b_{pl}=5.08\text{ mm}$. Figure 13 shows 3D EM model of this filter.

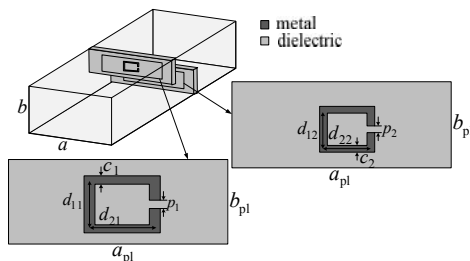


Figure 13 - 3D EM model of the dual-mode BSWF (model 3)

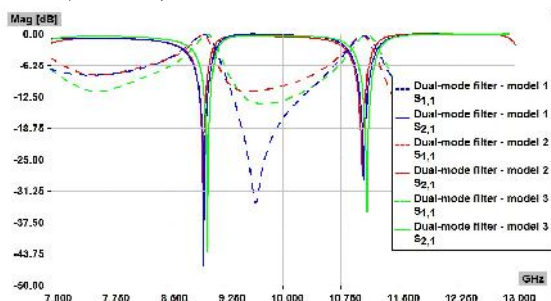


Figure 14 – Comparison of frequency responses of the dual-mode BSWFs (model 1, 2, 3)

For the previously described models of the filters, frequency responses are compared and the results are given in Figure 14. It can be concluded that proposed

realization of the inserts practically eliminates the mutual coupling between the SRRs, so each one of them can be independently tuned for the required resonant frequency. Also, the return loss has the lowest values beyond the stop band for the model with reduced dielectric plates, compared with the models when the plates cover the entire cross-section of the waveguide.

Further are described filter models using inserts realized as dielectric plates, connected to the upper and the lower waveguide walls by thin dielectric strips (SRRs of type 3). First, the model of the filter having two plates in the same transverse plane is made. The plates are mutually connected by means of thin dielectric strip and each one of them is connected to the upper and the lower waveguide wall using the strip of same width (Figure 15). Dimensions of both plates are set to $a_{pl}=7\text{ mm}$ and $b_{pl}=4\text{ mm}$, and the parameters of the SRRs are given in Table 4. The distance between the plates is chosen in such a way that the mutual coupling of the SRRs is eliminated, so the resonant frequencies can be independently tuned. In the considered example, this distance is set to $r=1.7\text{ mm}$.

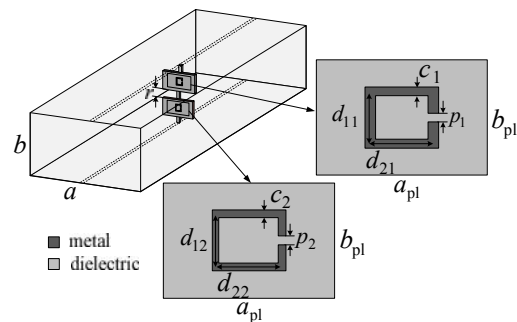


Figure 15 - 3D EM model of the dual-mode BSWF (model 4)

Table 4. Dimensions of the SRRs given in Figure 5

Resonant frequency	d_{1i} [mm]	d_{2i} [mm]	c_i [mm]	p_i [mm]
$f_0 = 9\text{ GHz}$ ($i = 1$)	2.5	4.9	0.2	0.9
$f_0 = 11\text{ GHz}$ ($i = 2$)	2.5	3.6	0.2	0.9

The last considered model of the dual-mode BSWF in this section is also based on the implementation of the SRRs of type 3, but in this case plates are placed in different transverse planes and they are mutually separated by the distance of $(\lambda_{g9\text{GHz}} - \lambda_{g11\text{GHz}})/4 = 3.68\text{ mm}$. The positions of the plates in these planes are chosen in such a way that the positions of the SRRs coincide with those used for the previously described model (model 4), in case when the distance between the plates is set to $r=1.7\text{ mm}$. 3D EM model of the filter is depicted in Figure 16. Dimensions of the SRRs are given in Table 4, and the

plates have the same dimensions as those used in model 4.

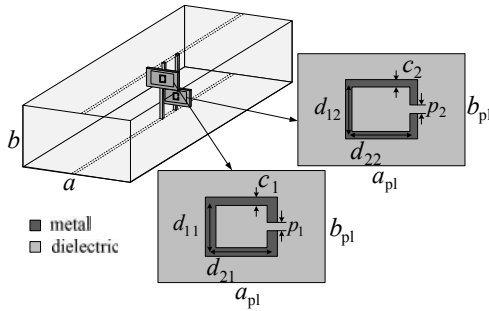


Figure 16 - 3D EM model of the dual-mode BSWF (model 5)

For these two models, frequency responses are also compared. Results are given in Figure 17 and one can see that the mutual coupling is eliminated by employing the proposed realization of the SRRs. This conclusion is important for the design of multi-mode BSWFs, since the presented method provides the possibility to independently tune the SRRs for each resonant frequency.

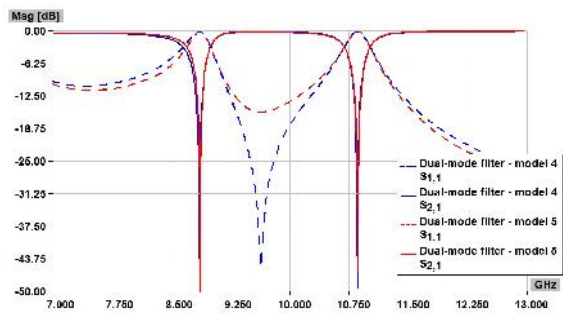


Figure 17 – Comparison of frequency responses of the dual-mode BSWFs (model 4, 5)

4. SINGLE-MODE AND DUAL-MODE THIRD ORDER BANDSTOP WAVEGUIDE FILTERS

The SRRs realized on dielectric plates, connected to the upper and the lower waveguide walls using thin strips, are employed for the design of the third-order BSWFs. This type of resonator provides the lowest values of the return loss beyond the stop band, compared with other proposed models. In this manner, filters with resonant frequencies of $f_0=9$ GHz and $f_0=11$ GHz are realized, by choosing the proper positions of the resonators. Dual-mode third-order BSWF is also modeled. It has two resonant frequencies ($f_{01}=9$ GHz, $f_{02}=11$ GHz), and each of its two stop bands has a bandwidth of 335 MHz. It should be emphasized that the parameters of the SRRs are slightly modified, compared with the values used for the models in the previous section, in order to achieve required resonant frequencies and bandwidth.

First, the third-order filter with resonant frequency of $f_0=9$ GHz is modeled. 3D EM model of this

filter is depicted in Figure 18. The model of the filter is realized by moving the plates up for $s_u=2.85$ m, related to the central position, and the parameters of the SRRs (Table 5) are tuned in such a way that the required resonant frequency of 9 GHz can be achieved. Each plate is of the same size ($a_{pl}=7$ mm, $b_{pl}=4$ mm) and they are mutually separated by the distance of $\lambda_{g,9\text{GHz}}/4=12.17$ mm.

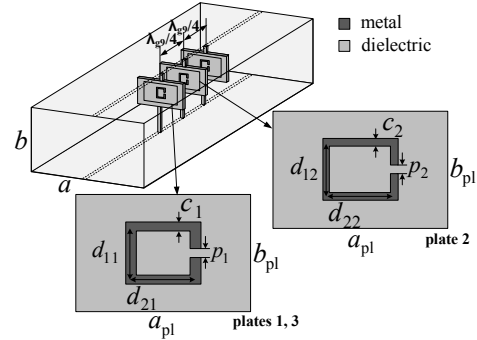


Figure 18 - 3D EM model of the third-order BSWF ($f_0=9$ GHz)

Table 5. Dimensions of the SRRs for the third-order BSWF with $f_0=9$ GHz

Dimension	d_{1i} [mm]	d_{2i} [mm]	c_i [mm]	p_i [mm]
Plates 1 and 3 ($i=1,3$)	2.50	4.75	0.18	0.90
Plate 2 ($i=2$)	2.50	4.75	0.16	0.90

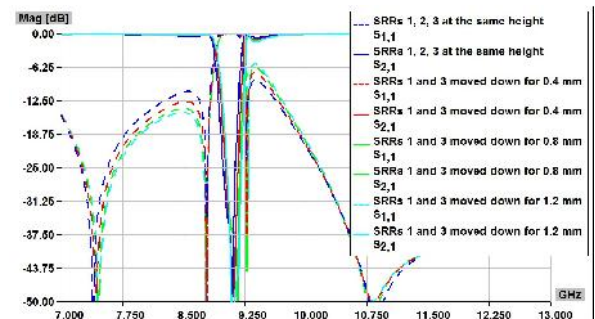


Figure 19 – Comparison of frequency responses of the third-order BSWF ($f_0=9$ GHz)

For this filter, frequency response is analyzed in case when the first and the third plate are moved down, related to the central position, so they are placed at the lower position, compared with the second plate. The other parameters of the filter remain unchanged. Compared frequency responses are shown in Figure 19 and it can be concluded that this change of the position of the plates affects only the return loss beyond the stop band, while the resonant frequency and bandwidth are practically unchanged. Therefore, if the fabrication technology does not allow completely precise positioning of inserts in the waveguide filter, deviations of this type do not influence the filter response significantly.

Next, the third-order filter with resonant frequency of $f_0=11$ GHz is modeled. 3D EM model of this filter is shown in Figure 20. This filter is realized by moving the plates down for $s_d=2.85$ mm, related to the central position, and the parameters of the SRRs (Table 6) are tuned in such a way that the required resonant frequency of 11 GHz can be achieved. Each plate is of the same size ($a_{pl}=7$ mm, $b_{pl}=4$ mm) and they are mutually separated by the distance of $\lambda_{g\ 11\text{GHz}}/4=8.49$ mm.

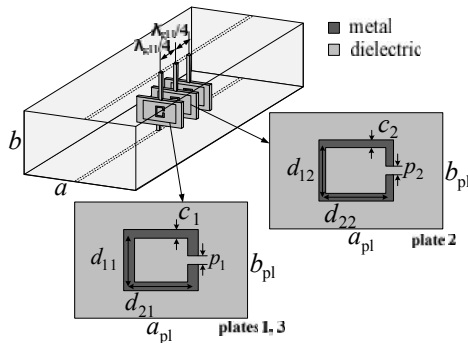


Figure 20 - 3D EM model of the third-order BSWF ($f_0=11$ GHz)

Table 6 - Dimensions of the SRRs for the third-order BSWF with $f_0=11$ GHz

Dimension	d_{1i} [mm]	d_{2i} [mm]	c_i [mm]	p_i [mm]
Plates 1 and 3 ($i=1,3$)	2.50	3.53	0.40	0.90
Plate 2 ($i=2$)	2.50	3.53	0.36	0.90

Finally, the dual-mode third-order BSWF is also realized. Namely, the proposed model, using previously described SRRs can be applied for the design of multi-mode bandstop filters, and the dual-mode bandstop filter is an example of presented solution. The idea is to use corresponding SRRs and place them at the proper positions in the transverse planes of the waveguide, in order to obtain dual-mode filter with two resonant frequencies, $f_{01}=9$ GHz and $f_{02}=11$ GHz.

3D EM model of the novel dual-mode third-order BSWF is shown in Figure 21. Resonators have the same positions as in the described single-mode third-order filters, i.e. the inserts are mutually separated by the corresponding distances: the distance between the SRRs with $f_{01}=9$ GHz is set to $\lambda_{g\ 9\text{GHz}}/4=12.17$ mm, and between those with $f_{02}=11$ GHz is set to $\lambda_{g\ 11\text{GHz}}/4=8.49$ mm. According to that, the distance between the SRRs with different resonant frequencies is set to $(\lambda_{g\ 9\text{GHz}} - \lambda_{g\ 11\text{GHz}})/4=3.68$ mm. It is important to emphasize that the dimensions of the SRRs are the same as for the individual third-order filters, and they are given in Tables 5 and 6. Related to the central position in the given transverse plane, SRRs with $f_{01}=9$ GHz are moved up for $s_u=2.85$ mm, and those

with $f_{02}=11$ GHz are moved down for $s_d=2.85$ mm. This is done in order to eliminate the mutual coupling of the SRRs in the same transverse plane. WIPL-D model of this filter is shown in Figure 22.

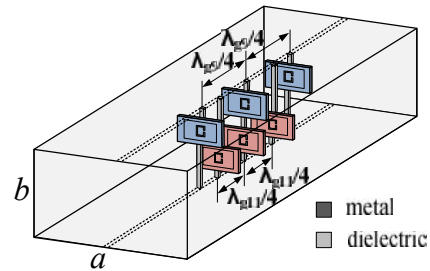


Figure 21 - 3D EM model of the dual-mode third-order BSWF ($f_{01}=9$ GHz, $f_{02}=11$ GHz)

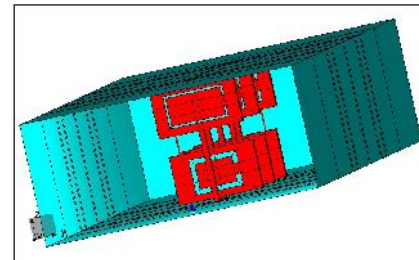


Figure 22 - WIPL-D model of the dual-mode third-order BSWF ($f_{01}=9$ GHz, $f_{02}=11$ GHz)

The frequency response of the dual-mode BSWF is compared with the responses of the individual single-mode filters and these results are given in Figure 23. For the individual filters, the following values of the resonant frequency and bandwidth are achieved: $f_0=9.062$ GHz and $B_{3\text{dB}}=333$ MHz, $f_0=11.037$ GHz and $B_{3\text{dB}}=333$ MHz. For the dual-mode third-order BSWF, the following values of the resonant frequency and bandwidth are achieved: for the first stop band $f_{01}=9.036$ GHz and $B_{3\text{dB}}=340$ MHz, and for the second stop band $f_{02}=11.031$ GHz and $B_{3\text{dB}}=332$ MHz. According to this, the design requirements are accomplished. Based on the compared results, it can be noticed that the obtained responses are matched relatively good. Thus, it can be concluded that the dual-mode BSWF can be independently tuned for each resonant frequency, which is important for the design of multi-mode BSWFs.

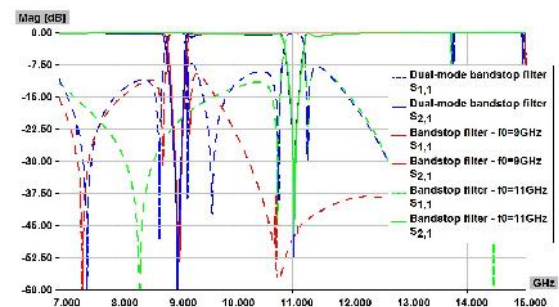


Figure 23 – Comparison of frequency responses of the dual-mode BSWF and individual BSWFs

5. CONCLUSION

Various models of the BSWF are presented. For these filters, printed-circuit inserts with SRRs are implemented in the transverse planes. Several realizations of the single-mode and dual-mode SRRs are proposed and the filter response is analyzed depending on the parameters of the SRRs and their position in the waveguide. It is proved that the inserts realized as dielectric plates, connected to the upper and the lower waveguide walls by thin strips, provide the lowest values of the return loss beyond the stop band, compared with the models having inserts across the entire and a half of the waveguide cross-section. Dual-mode BSWFs are realized by means of various implementations of these inserts and it can be concluded that the proposed design provides the possibility to realize multi-mode bandstop filter, and each resonant frequency can be independently tuned. Single-mode and dual-mode third-order BSWFs, realized using suitable combinations of the considered inserts, are presented as examples of practical implementation. The conclusion related to the possibility to independently control resonant frequency for each stop band is confirmed. This result is important for the design of multi-mode bandstop waveguide filters.

6. ACKNOWLEDGEMENT

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REZIME

NOVA REALIZACIJA FILTERA NEPROPUSNIKA OPSEGA UČESTANOSTI U TALASOVODNOJ TEHNICI

U radu se prikazuju različiti modeli talasovodnih filtara nepropusnika opsega učestanosti zasnovanih na polutalasnim rezonatorima u obliku kvadrata sa prerezom. Predlažu se novi rezonatori ostvareni u tehnici mikrotrakastih vodova, a primenjuju se kao prepreke u poprečnim ravnima talasovoda. Ovi rezonatori se projektuju tako da imaju jednu odnosno dve rezonantne učestanosti. Odziv filtara se analizira u zavisnosti od različitih parametara rezonatora, uključujući i njihov položaj. Razmatraju se talasovodni filtri projektovani pomoću različitih struktura prepreka sa polutalasnim rezonatorima u cilju dobijanja filtara koji pokrivaju jedan odnosno dva opsega učestanosti. Razvija se novi postupak projektovanja koji omogućava realizaciju filtara nepropusnika više opsega učestanosti, a prikazuju se filtri koji pokrivaju dva opsega učestanosti kao primeri praktične primene.

Ključne reči: polutalasni rezonator, talasovodni faltar nepropusnik opsega

Generator Voltage Control in Serbian Electric Power System - Identification of the Model Structure and Parameters

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This paper presents one way of structure and parameters identification of the generator voltage regulation model within Serbian electric power system. These models are commonly used in dynamic security analysis of the interconnected power systems. This was preceded by the appropriate on site testing. Present state of the voltage control in the Serbian power system is given, as well as procedure for determining regulator parameters based on its step response. Model verification is illustrated on the example of TPP Nikola Tesla A1, by simulating step responses from the on-site testing.

Key words: *identification, structure, parameters, model, regulation, excitation, generator, Serbian Electric Power system*

1. INTRODUCTION

The issue of adequate mathematical modeling for the security analysis of the contemporary interconnected power systems (IS) is one of the most important and one of the most complex problems. Mathematical models have to cover very complex processes, which are affected by components of complex structure. Within security analysis of the IS, functioning of the IS, as a whole was analyzed. Therefore, special attention was paid to mathematical models, which are usually used for this type of analysis.

Dynamic security analysis requires inclusion of excitation system transient states, especially for the analysis of short-term dynamic processes. Within this type of analysis, effects of rapid short-term (up to 10 s) dynamic processes are being followed and special attention is paid to aspects of transient (in)stability.

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Modeling of the generator excitation controllers for dynamic security analysis is subject of many papers. Instead of citing all these papers, survey on excitation systems and their controllers [1] is cited, which presents models of various structure and complexity, depending both on the transition process and type, purpose and complexity of the analysis. Standardized IEEE models of generator excitation control system [1-9] have been used in the Institute "Nikola Tesla" previously. These models are also present in PSS/E-29 [10] and DIGSILENT Power Factory, Version 14 [11].

Proposed models respected the North American practice only; therefore, they could not be used as standard models in the other parts of the world. Despite IEEE standardization, not all excitation systems were covered, for example multivariable excitation system, which is used in Serbian power system (HPP Djerdap 1 and HPP Djerdap 2). Therefore, model of multivariable generator excitation controller [12] has been developed for the analysis of various dynamic states of Serbian power system and its surrounding.

The main objective of this paper is to present adequate modeling of the generator excitation system and

its controller, for the analysis of dynamic security of IS, fully respecting the current state of the Serbian power system. In addition to the above, references [13-16] were used as well as the experimental results of the study "System parameters of voltage and frequency control within Serbian power system (phase I)", which Institute Nikola Tesla produces for Public Enterprise Electric Power Industry Serbia (EPS). Main objective of this study is to examine, record, test, analyze and adjust the relevant parameters of the excitation control and turbine control of all generator units within EPS.

During the study, appropriate complement of the initial mathematical model of excitation control system has been formed, according to the experimental results. Structure of the model was determined and its relevant parameters were quantified in order to get closer to the actual state of the voltage control in the Serbian power system. General structure and the functional block diagram of the excitation control system, present state of the excitation control in the Serbian power system is presented in [17].

The first complement is related to the implementation of the (stator) voltage droop coefficient, which was quantified within field tests. Influence of the voltage droop coefficient to voltage-reactive states of the transmission network has been analyzed separately. Static and dynamic aspects of the voltage droop coefficient are considered in [18] and [19] respectively. Importance of voltage droop coefficient and the impact of its proper setting to established post dynamic voltage-reactive states were determined within Serbian transmission network (and its surrounding). At the same time, amendments to transmission grid code were proposed in order to adapt it to real needs and capabilities of Serbian power system, with regard to establishing desirable voltage-reactive states.

The other complement of the mathematical model is related to inclusion of the integral action of the excitation control, field forcing and rotor current feedback.

In the previous part of text, current activities were analyzed considering adequate modeling of generator's excitation control system in Serbian power system. The mayor part of these analyses is in publication process. The way of determining and verifying the model structure and parameters of the excitation system is left to be publishes and it is the subject of this paper.

This paper presents a generalized model of the generator excitation controllers. Afterwards, the content and purpose of the excitation system field test in Serbian power system are given. As a typical example, field test results of the excitation control system for TPP Nikola Tesla A1 are presented. For the same generator, procedure for determining controller parameters, based on stator voltage and excitation voltage

response is described. At the end, developed model of the excitation controller has been verified by comparing measured and simulated respond traces for the same disturbance ($\pm 10\%$ step change of voltage reference).

2. DEVELOPED GENERALIZED MODEL OF GENERATOR EXCITATION CONTROL SYSTEM

Development chronology of the excitation control system model is summarized in the introduction of this paper. The proposed complement of model for multivariable control system is exposed then, with a particular emphasis on activities during the study "System parameters of voltage and frequency control within Serbian power system (phase I)". These activities have contributed to expansions of developed mathematical model of excitation control system, according to the results of field test results: model structure has been determined and its relevant parameters have been quantified, in order to get closer to the actual state of the voltage control in the Serbian power system.

2.1. Generalized model of generator excitation control system

Figure 1 shows the structural diagram of developed model, which includes field forcing [17] (which was not possible to show). Input signal of the voltage channel is given by:

$$\Delta V = V_{REF} + V_S - V_r - V \quad (1)$$

Where:

V_{REF} - reference stator voltage;

V_S - voltage component due to droop;

V_r - voltage component due to rotor current feedback;

V - stator voltage actual value.

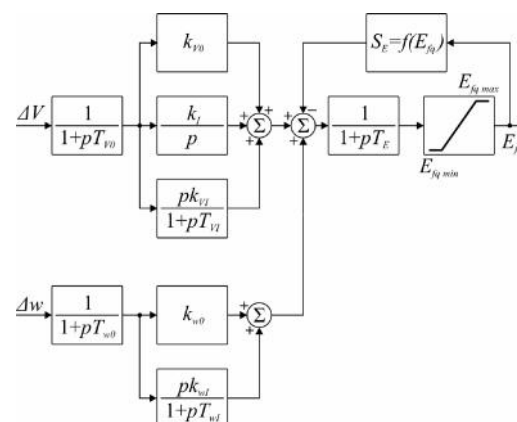


Figure 1 - Structural diagram of the multivariable excitation system

Meaning of the labels in Figure 1:

T_V, T_{VI} - time constants of the voltage channel;

k_{V0}, k_{VI} - voltage channel gain (zero and first derivative);

k_{w0}, k_{wi} - frequency channel gain (zero and first derivative);

T_w, T_{wi} - time constants of the frequency channel;

k_I - integral gain;

T_E - time constant of the excitation system;

E_{fq0} - electromotive force which is proportional to the excitation voltage in the initial steady state;

$f_{sat}(E_{fq})$ - effect of magnetic saturation (only with electro-mechanical system excitation).

Model input depends on voltage controller type. As already mentioned, Figure 1 shows the structural diagram of the multivariable excitation system, with input channels for voltage, frequency and their first derivatives changes.

The main feature of this model is flexibility. Its general form can be reduced to the existing well-known models by the appropriate parameters setting. Developed model is fully compliant with the basic characteristics of a voltage control within Serbian power plants [17]. Developed generalized model can be simply reduced to a model with proportional control of the stator voltage, which is present in all Serbian power plants, except HPP Djerdap 1 and HPP Djerdap 2, which use unreduced model shown in Figure 1. Developed model also covers effects of magnetic saturation (for electromechanical excitation systems).

The output of the model is excitation voltage as seen from the stator i.e. electromotive force E_{fq} (input of the generator model) [20]. Model output E_{fq} is subjected to so-called hard limits (upper and lower ceiling voltage). Output of static excitation systems directly depends on its supply voltage (generator voltage or voltage of the own consumption).

3. DETERMINATION OF THE MODEL STRUCTURE AND PARAMETERS

3.1. The content and objective of the field tests

For the modeling of excitation control system, field test results of the study "System parameters of voltage and frequency control within Serbian power system (phase I)", have been used. At the time of writing this paper, field test were carried out for the following units (in chronological order):

- B u HPP Potpeć (2010, October),
- A2 u TPP NT A (2011, May),
- 1 u HPP Vrla 1 (2011, August),
- HPP Uvac (2011, August),

- A1 u TPP NT A (2011, August),
- A5 u TPP Kolubara (2011, August),
- B1 u TPP Kostolac (2011, September),
- A1 u TPP Kostolac (2011, September),
- A6 u TPP NT A (2011, September),
- A4 u HPP Đerdap 2 (2011, September),
- B u HPP Kokin Brod (2011, September),
- A u HPP Bistrica (2011, October),
- A2 u HPP Pirot (2011, November),
- A5 u TPP NT A (2011, November),
- B u HPP Vrla 2 (2011, December),
- TPP Morava (2011, December),
- G4 u HPP Vrla 1 (2011, December),
- B1 u TPP TENT B (2012, November),
- A3 u HPP Đerdap 2 (2012, November) and
- A u HPP Vrla 4 (2012, December).

Each technical report of the Institute "Nikola Tesla" on field test results contains measured traces of the excitation voltage and stator voltage or excitation current and dynamic characteristics of the excitation controllers, defined by its continuous domain transfer function (for excitation current controllers and excitation voltage controllers). Then, method for determining controller parameters based on the response was shown (determining parameters of the excitation current controller based on the excitation current response and determining parameters of excitation voltage controller based on responses of stator voltage and excitation voltage). Calculation of voltage droop at generator busbar (σ_g) and at HV busbar (σ_m) is given. At the end of each report, table of characteristic parameters is given.

In this paper, on the example of generator A1 in TPP Nikola Tesla A, determination and verification of the structure and parameters of the excitation control system model will be illustrated. The described procedure was applied with all previously mentioned generators for which field test were carried out.

3.2. Field test results for TPP Nikola Tesla A, generator A1

Field test for TPP Nikola Tesla A, generator A1, have been carried out during August, 2011. Generator A1 ($P_n=210$ MW, $U_n=15.75$ kV) is equipped with static excitation system and automatic voltage regulator. Nominal excitation voltage is 424 V and nominal excitation current is 1 930 A.

Results of the field test of the TPP Nikola Tesla A, generator A1, are summarized in technical report [21], whose contents has already been explained. It should be noted that the form of technical reports on

all tested generators is the same. After measured traces of the excitation voltage, excitation current and stator voltage, a method for determining the dynamic characteristics of the stator voltage controller and excitation current controller are given, i.e. parameters identification of equivalent linearized model of thyristor converter as well as controller parameters identification. Analysis of the whole power system require only automatic mode of operation of voltage controller. Therefore, it will be explained in detail in the rest of the text.

The transfer function of the voltage controller, which is designed and manufactured at the Institute "Nikola Tesla", in continuous time domain is given over an equivalent model [21]. Equivalent model contains two parts: a linear controller and the equivalent model of the thyristor bridge, which is linearized around the point of nominal operation. In the case of static excitation systems, the equivalent gain of the thyristor bridge was measured at nominal stator voltage (excitation transformers i.e. thyristor bridges are supplied from the generator busbar).

According to the analysis, which is explained in detail within technical report for generator A1 in TPP Nikola Tesla A [21], transfer function of the voltage controller in the continuous domain is:

$$G_{ns}(s) = K_{ns} \cdot \frac{s + c_{ns}}{s} \cdot \frac{I}{T_{TM}s + 1} \quad (2)$$

Where:

K_{ns} - equivalent gain of the voltage controller and thyristor bridge (experimentally determined value $K_{ns} = 0.21$ V/V);

T_{TM} - time constant of the thyristor bridge (experimentally determined value $T_{TM} = 0.0011$ s);

c_{ns} - value for which the numerator of the PI transfer function becomes zero (determined value 0.6 rad/s).

For the generator A1 in TPP Nikola Tesla A, linearized transfer function, including dynamics of the thyristor bridge is:

$$G_{scm}(s) = 0.21 \cdot \frac{s + 0.6}{s} \cdot \frac{I}{0.0011s + 1} \quad (3)$$

Within the field test, it was found that the voltage droop at the generator busbar (σ_g) is set to zero, which is not good in terms of established post-dynamic quasi-stationary states. Influence of the voltage droop on established post-dynamic quasi-stationary states is described in [18, 19].

Technical report [21] contains characteristics of the excitation limiter. Limiter of the maximal excita-

tion current is set to 2 123 A. Limiter of the maximal stator current is set to 9.955 kA.

Limiter of the minimal excitation current (under excitation limiter) is defined by the linear equation in P - Q plane, in capacitive quadrant of the capability curve. The line passes through two points $(P, Q) = (0, Q_1)$ and $(P, Q) = (P_{nom}, Q_2)$:

$$Q_{min} = Q_1 + \frac{Q_2 - Q_1}{P_{nom}} \cdot P \quad (4)$$

Where: $Q_1(P=0) = -26.2$ Mvar, and $Q_2(P=P_{nom}) = 0$ Mvar.

Need for generator operation in under-excited regimes, in the Serbian power systems, for the time horizon of 2025. year, is analyzed in [22]. The results of the analysis of the Serbian power system under minimum load conditions for said time horizon, indicate the great practical importance of the proper setting of the reference generator voltage and its influence on the established voltage-reactive states.

Application of the developed method for managing generator voltages [24] - [28], pointed out real capabilities for the rationalization of under-excited regimes, when the inevitable "burden" of these regimes, is distributed evenly over generators, according to their capabilities and limitations. In this context, it is essential to have correct setting of the under excitation limiter.

Field forcing parameters are also given in [21]. These parameters are very important for short-time dynamic processes, where analysis of transient (in-)stability is dominant. Field forcing threshold is 11 025 kV and forcing current is 3 088 A. Maximum duration of the forcing is 10 s, and the duration of the pause between forcing is 900 s.

Generator A1 in TPP Nikola Tesla A is equipped with static excitation system, with digital automatic voltage regulator. According to experimentally determined parameter values (K_{ns} and c_{ns}) and appropriate base values for the excitation voltage, proportional and integral gains (k_{v0} and k_I) can be calculated. Time constant of the thyristor bridge T_{TM} corresponds to the time constant of excitation systems T_E .

In that way, normalization has been performed according to the accepted base values, as well as appropriate data for the computer programs *PRIMCONT* and *DINST* [20]. In other words, link between field test results and dominant parameters of the developed model is established.

3.3. Model verification

In order to verify developed mathematical model of the excitation control system, special version of the computer program *DINST* have been developed (*DINST RED*).

This version has been adapted to the field test conditions of the analyzed generator. Its main feature is determination of dynamic response of the excitation system to a predefined step reference change (for example from 90% to 100%), in automatic mode, for not-loaded generator.

Figure 2 and Figure 3 show response of the excitation system for the step reference change, in automatic regime, for not-loaded generator A1 in TPP Nikola Tesla A. Experimental results are compared to

simulated responses, by using modified version of the computer program *DINST* (*DINST RED*).

In Figure 2 and Figure 3, $V_{g,mer}$ (generator voltage), $V_{f,mer}$ (excitation voltage) and $I_{f,mer}$ (excitation current) are measured traces. $V_{g,DINST}$ (generator voltage), $E_{QE,DINST}$ (electromotive force proportional to excitation voltage) and $EMQ,DINST$ (electromotive force proportional to excitation current) are results of simulations.

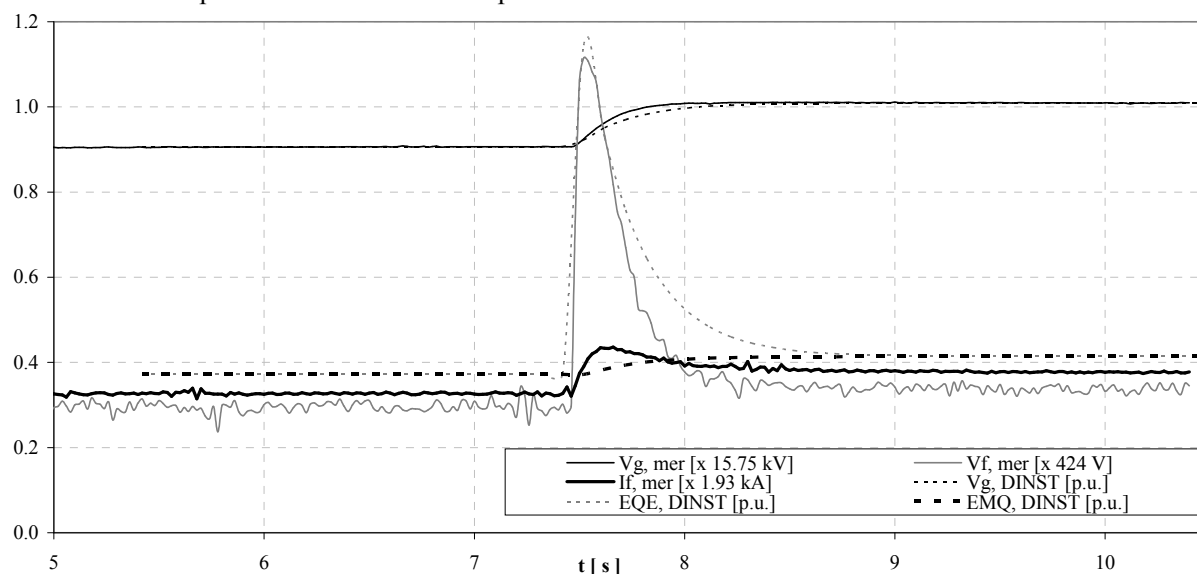


Figure 2 - Response of the excitation system for the step reference change from 90% to 100%

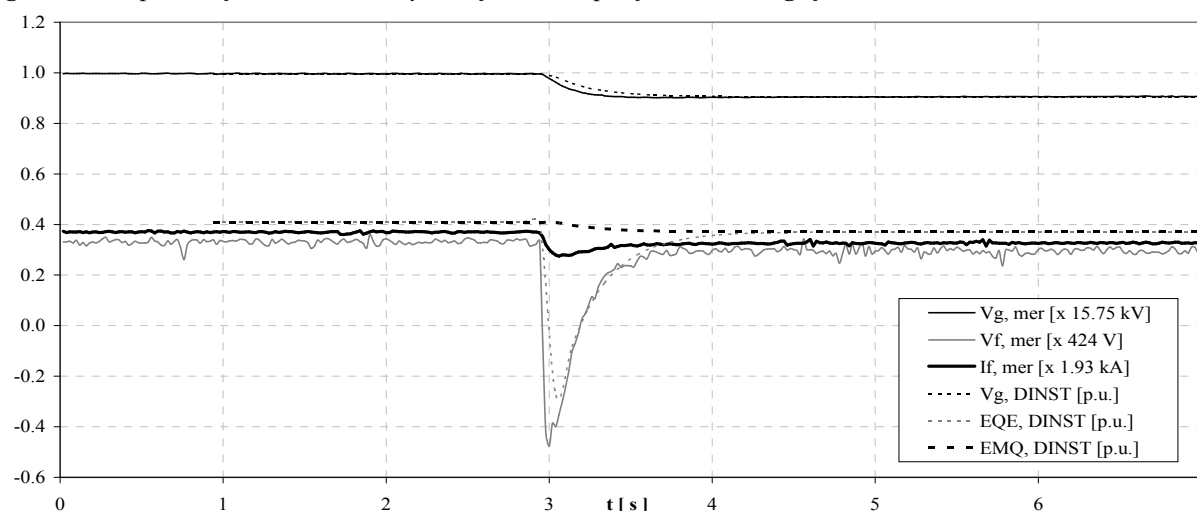


Figure 3 - Response of the excitation system for the step reference change from 100% to 90%

Comparison of measured traces and simulated response indicates their high correlation i.e. quality of identified structures and parameters of the excitation control system model.

3.4. Concluding Remarks

The described method was applied to all previously mentioned generators, for which field test were carried out. In that way, relevant parameters of the

excitation system and excitation control system were obtained. These parameters were used for simulations.

Technical reports of the Institute "Nikola Tesla" on generators for which field test were carried out so far, are systematized in a separate volume of the study. It was found that the resulting dynamic responses show that the values of all parameter result sa-

tisfactory dynamics for excitation, de-excitation and disturbances, which affect excitation control system. Further, it was stated that after field tests excitation systems are ready for all planned modes of operation.

4. CONCLUSIONS

This paper presents one way of identifying structure and parameters of the excitation control system model. This method was applied to all generators for which field test were carried out so far. At the same time, it allows for the complete correspondence between the data obtained by field test measurements and dominant parameters of developed mathematical model. Simulations were performed by using developed model and obtained parameter values, in order to quantify operation of the primary voltage control within Serbian power system. The results of these simulations will be the subject of a separate paper, which is being prepared.

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REZIME

IDENTIFIKACIJA STRUKTURE I PARAMETARA MODELA SISTEMA REGULACIJE POBUDE GENERATORA U EES SRBIJE

U radu je izložen jedan od načina identifikacije strukture i parametara modela sistema regulacije pobude generatora u EES Srbije. U pitanju su modeli koji se uobičajeno koriste u analizama dinamičke sigurnosti elektroenergetskih interkonekcija. Tome su, uz presek sadašnjeg stanja ove regulacije u EES Srbije, prethodila odgovarajuća eksperimentalna merenja, koja su po svojoj suštini i karakteru odgovarala zadatom cilju. Prikazan je način određivanja parametara regulatora na osnovu odziva regulisanih i upravljačkih veličina (napona statora i napona pobude). Na primeru generatora A1 u TE Nikola Tesla, izvršena je verifikacija novoformiranog matematičkog modela sistema regulacije pobude, simulacijama poremećaja izvršenih u okviru sprovedenih eksperimenata.

Ključne reči: *identifikacija, struktura, parametri, model, sistem regulacije, pobuda, generator, EES Srbije*

TEHNIKA

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Determination of the Parameters on Which Parking Search Time Depends

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Cruising for parking is a topic that has been neglected for many years. Currently, its influence on traffic congestion, fuel consumption and pollution has been recognised, and therefore, this issue has become increasingly significant and topical. In this work, the causes that lead to parking searches are examined, and the parameters that affect parking search time are investigated based on data gathered in the Belgrade central area. Operational use of the obtained conclusions could influence the identified parameters and reduce the parking search time as well as the associated adverse effects.

Key words: parking search time, parking occupancy level, parking policy

1. INTRODUCTION

As a result of high parking occupancy levels in inner city areas, many drivers find themselves in the following situation: upon arrival at their destinations, they are forced to continue driving to find vacant parking spaces. Such continued driving results in additional time and money costs to the drivers but also causes frustration and dissatisfaction with the transportation system. Therefore, drivers value the time that they spend searching for a parking space far more highly than the travel time [1]. Based on the available literature [2], the parking search time in city central areas is between 3.5 and 14 minutes (approximately 8 minutes).

However, the negative consequences not only directly affect the parking searchers but also society as a whole. Cruising for parking increases traffic volume. It is estimated that between 8 and 74 percent of the traffic in the central areas involves cruising for parking [2]. Such an increase in traffic volume further results in slower speeds, increased travel time and reduced level of service on the road network. In this manner, vehicles searching for a vacant parking space contribute to traffic congestion and thus have adverse effects on the economy, environment and quality-of-life in cities.

It should be noted that the influence of traffic due to cruising for parking on congestion is greater than the influence of through traffic [3] because such vehicles (due to search behaviour) move at a slower speeds and/or stop more frequently, thus causing additional disturbances to other road users [4].

The impact of parking searches on congestion has been unjustly neglected for many years, but recently, due to a realisation of its significance, this issue has become increasingly topical. Moreover, certain authors consider it an essential component of traffic congestion in cities [5]. In this work, the causes that lead to parking searches and the parameters that affect it are intensively examined to address this problem [2, 6, 7, 8].

It has long been recognised that the cause of parking searches is high levels of parking occupancy (utilisation). As parking utilisation increases, the probability of finding a vacant parking space decreases, and the search time and distance increases [4]. In this respect, the first models to address this topic applied correlation of parking search time/distance exclusively with parking occupancy [9, 10, 1, 11].

However, searching for parking is a far more complex process than was originally acknowledged. Recent studies show that in addition to parking utilisation at the moment of search, additional important factors include other drivers and trip characteristics.

Therefore, a parking space search has an individual character that must be examined, which has led to development of disaggregate parking search time models [8].

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The aim of this paper is to examine the parameters that influence parking search time and to quantify their influence using the example of the Belgrade central area.

The structure of the paper is described as follows. Section 1 describes the state of parking in the central area of Belgrade. Section 2 presents the problem posed in this paper and the procedure for addressing it. To implement this procedure, the necessary data were gathered on street parking spaces within the central area of Belgrade, and the survey methodology is described in Section 3. The gathered data were analysed and used to fit a logit model, as demonstrated in Section 4. The final considerations are presented in Section 5.

2. PARKING IN BELGRADE

The urban region of Belgrade occupies an area of approximately 77,000 ha and contains approximately 1.5 million inhabitants. Nearly 96,000 inhabitants live in the city centre, which has an approximate area of 440 ha.

The motorisation level in this area is approximately 300 cars per 1,000 inhabitants. Based on the traffic survey, the inhabitants of Belgrade make approximately three million trips per day. In the modal split, passenger cars account for 22%. The Master Plan of Belgrade 2021 predicts an increase in mobility and a slight increase in the number of inhabitants. Hence, it is expected that the total number of trips will reach close to 3.5 million trips per day [12].

The parking problem in Belgrade occurs in almost all of the urban area. This problem arises as a result of the mismatch between the parking demand and supply, which is a result of historically formed city structures, traffic flows or omissions in planning as well as the lack of good parking supply management.

In Belgrade, parking is managed in a limited area in its central area and a small number of parking spaces (approximately 5%) outside the central area [13]. In the central area, parking is managed in terms of on-street parking, off-street parking and parking garages. The basic characteristic of Belgrade is insufficient off-street public parking capacity such that the majority of vehicles are parked on the streets.

Similar to the central areas of most cities and in accordance with the modern concept of traffic management, a restrictive parking regime has been implemented within the central area for on-street parking spaces. The area is divided into three zones (i.e., Red, Yellow and Green) that differ in the following attributes: time limitation (1, 2 and 3 hours, respectively) and parking price (56, 38 and 31 RSD per comm-

enced hour, respectively)¹ The period of regime validity is every weekday from 7 a.m. to 9 p.m. and on Saturdays from 7 a.m. to 2 p.m.

Residents and businesses in the area are entitled to a parking permit (PP), which does not guarantee a vacant parking space to its holder; however, once the user finds a vacant parking space, the user can park there without any time limitation. Disabled persons can park at specially marked parking spaces (3% of the total number of parking spaces [13]), which the parking regime does not take into account. On-street parking spaces can be reserved for state institutions, city institutions, public services, diplomatic and other foreign representatives, businesses and entrepreneurs. The City Administration approves reservations based on previously prescribed conditions.

Parking in parking lots and garages is charged each day for a 24-h period. Payment is also charged per hour, and the price varies from facility to facility. A progressive tariff system is applied in the parking garages in which the first hour costs 75 RSD and each additional hour is 90 RSD. These rates do not apply to the Aleksandar Kostić garage, which applies a linear tariff system and a price of 100 RSD per hour. Depending on the facility, parking prices in off-street parking lots are approximately 80 RSD per hour (in the Kamenička, Slavija 1 and Slavija 2), 90 RSD per hour (in the Karađorđeva and Simpo) or 100 RSD per hour (in the Politika).

Under certain conditions, users can also purchase a monthly ticket and reserve a parking space in off-street parking lots and parking garages.

Utilisation of on-street parking spaces ranges from 0.99 (in the morning, when only residents are parked) up to 1.45. If we consider only non-reserved parking spaces, the maximum utilisation reaches as high as 1.88. Because of this occupancy of parking spaces (all parking spaces are occupied, and cars are also parked within locations where parking is forbidden), a vacant on-street parking space is difficult to find.

However, vacant parking spaces are always available in off-street parking lots and garages.

3. PROBLEM STATEMENT AND PROPOSED SOLUTION

As stated previously, the aim of this paper is to examine the parameters that affect parking search time and quantify their influence using the example of the Belgrade central area.

¹All prices shown refer to the period during which the survey was conducted (November and December, 2011). Currency rate was 1 EUR=100 RSD.

All users that are not guaranteed a vacant parking space are assumed to search for one. In analyzing the parking user categories (Section 1), it can be concluded that these users are all drivers except for those who have a reserved parking space. Therefore, these users are the subjects of further research.

The earliest studies showed that parking search time depends on parking utilisation at the moment of search. In addition, recent studies show that certain user and trip characteristics may also play a role, and in particular, the driver's prior knowledge of the parking situation and the driver's personal preferences [1]. The driver's knowledge is usually associated with his/her frequency of parking in that area as well as the trip length. Personal preferences include the importance that each user gives to travel cost, walking distance, etc.

Therefore, parking search time has an individual character that must be examined. Therefore, we decided to use selected disaggregated models that are based on individual users.

We chose the logit model because it is a disaggregated model that allows testing of the individual significance of a large number of parameters suspected to affect parking search time.

To conduct the modelling, it is necessary to collect data on user and trip characteristic that can affect parking search time (potential independent variables) and parking search time (dependent variable) based on the sample of users of non-reserved parking spaces in the Belgrade central area.

Using the model fitting, we identify parameters that significantly contribute to prediction of the output (parking search time) and quantify their impact.

4. SURVEY METHODOLOGY

The aim of the survey was to collect the data necessary for the model fitting that will identify the parameters that affect parking search time and quantify their impact.

The subjects of the survey are the users of non-reserved public parking spaces.

Based on the literature and experience [1, 8, 14], we surveyed the parameters that are expected to influence parking search time:

- Parking utilisation level at the moment of search – Higher utilisation levels refer to lower numbers of vacant parking spaces such that the parking search time is longer.
- Trip length – This parameter can be used as a proxy for knowledge of the local parking situation. It is believed that certain local users (users who travel shorter distances) have great know-

wledge of the parking situation in the area and thus find a vacant parking space faster.

- Parking frequency – Similar to the previous parameter, this one is related to knowledge of the local parking conditions. Increased parking frequency and user knowledge therefore decreases the parking search time.
- Parking purpose – Certain research shows that the parking search time can significantly differ among different parking purposes.
- User personal preferences – By ranking the parking quality parameters, users can express their personal preferences, which may offer an explanation for what may appear at first as irrational behaviour (e.g., the user's primary goal may not be to minimise the parking search time but to reduce the walking distance, reduce the trip costs or to avoid illegal parking).
- Parking search strategy – "Parking search strategy is used to denote the set of behavioural rules adopted by a driver to find a parking space for a particular activity on a particular day" [1]. Although certain authors distinguish among a number of different strategies [15], previous studies under similar conditions set aside only two [14]: the user first arrives at the destination and subsequently begins to look for parking or the user searches in advance while approaching the destination.

In addition to these parameters, which are the potential independent variables of the model, we surveyed the dependant variable of parking search time. This variable is surveyed according users' statements on how long they searched: not at all, up to five minutes, five to 10 minutes or more than 10 minutes [16]. Although the parking search time based on users perception may seem imprecise, this is one of the generally accepted methods for its determination.

These parameters were surveyed using face-to-face interviews with users. The exception was parking utilisation level at the moment of search, which was surveyed using a combination of interviews and counting. In general, the moment of parking (which is close to the moment of search) was determined by interview, whereas parking utilisation at a moment in time was determined by counting of parked vehicles. The parking utilisation levels at the end of each 15-minute interval were taken from the study "Parking management strategy" [13].

The survey was conducted using on-street parking spaces in the central area of Belgrade. Street sections were selected within the Red and Green zones (specifically in the area of the Clinical Centre of Serbia)

and were chosen such that a wide range of parking utilisation could be expected, among other factors.

We did not conduct surveys in off-street parking lots and garages because a vacant parking space can be found in these locations at any time, and thus, no searches occur (Section 1). Additionally, a small amount of users who park off-street will have previously searched for on-street parking spaces [17].

The time of the survey was the valid period of the parking regime (from 7 a.m. to 9 p.m.). The survey was carried out during five days in November and December 2011.

5. MODEL FITTING

In total, 523 users were interviewed. The distribution of users according to the surveyed parameters is shown in Table 1.

Table 1. Distribution of on-street parking users

Characteristic	Category	Frequency	Percentage
Parking utilisation level	Average	1,49	
Trip length (km)	Average	30,0	
Parking frequency	Often	313	60,1
	Periodically	103	19,8
	Rarely	105	20,1
Parking purpose	Residential	81	15,6
	Shopping	24	4,6
	Work	49	9,4
	Leisure	43	8,3
	Business	101	19,4
	Private business	222	42,7
Personal preferences	To find a parking space	247	48,1
	Closer to a destination	136	26,5
	Cheaper parking	30	5,8
	Vehicle safety	100	19,5
Parking search strategy	Searches after reaching the destination	289	68,3
	Searches in advance	134	31,7
Parking search time	Without searching	307	59,3
	Up to 5 minutes	111	21,4
	5 to 10 minutes	45	8,7
	More than 10 minutes	55	10,6

This database was used to fit the logit model. The model is fit by identifying the characteristics that significantly affect parking search time and estimating the regression coefficients via the maximum likelihood method (which quantifies the impact of the selected characteristics). Because the dependent variable has a natural ordering (0 minutes, up to 5 minutes, 5 to 10 minutes and over 10 minutes), an ordinal regression model was used.

Not all respondents answered all of the questions, and certain cases were missing a subset of the an-

At the moment of search, the utilisation level of non-reserved on-street parking spaces ranged between 0.88 and 1.88, with an average value of 1.49. The average trip length was 30.0 km because many patients from other cities travel to the Clinical Centre of Serbia.

The majority of users (60.1%) park in the zone quite often (a few times a week). Among the parking purposes, private business predominates (42.7%). The most important factor for users is to find a parking space (48.1% chose this parameter as their primary goal), and the majority (68.3%) look for a parking space upon arrival at the destination.

The parking search time is 2.5 minutes on average (59.3% of users do not search at all, whereas others spend 6.2 minutes on average).

wers. It was assumed that this oversight occurred by accident (respondents in a rush did not answer all of the questions or the interviewer skipped a question or writing an answer) such that respondents who did not give all of the answers do not differ from those who did. In this sense, we applied case-wise deletion [18], which means that we removed from the database all cases with missing data on any variable to be included in the model. The model was fitted using a subset of cases for which data on all variables were complete.

The model results are shown in Table 2.

The test of the full model compared with the intercept-only model was statistically significant, indicating that the set of independent variables reliably predicts the parking search time ($\chi^2=70,037$; $df=2$; $p<0,000$).

Only 4.2% of the absolute values of the Pearson residuals were greater than 1.96, and only 1.5% greater than 2.58.

The test of parallel lines rejects the null hypothesis ($\chi^2=4,485$; $df=4$, $p<0,344$), thus confirming that it is justifiable to use the same regression coefficients for all categories of variables, i.e., to use the ordinal regression model.

Table 2. Ordinal regression model results

Variable	Parameter estimate (β)	SE	Sig.	Exp (β)
Search time = 0 minutes	1,245	0,647	0,054	
Search time = up to 5	2,372	0,653	0,000	
Search time = 5 to 10	3,220	0,663	0,000	
Parking utilisation level	1,205	0,395	0,002	3,337
Parking strategy (1 st)	-1,411	0,219	0,000	0,244

*Number of observations: 414

The results show that parking search time is significantly affected by two parameters: parking utilisation level at the moment of search and parking search strategy. The relationships of these parameters with the parking search time are described in the following (Table 2):

If the parking utilisation level at the moment of search is high, users will require additional time to find a vacant parking space.

Users who reach the destination and subsequently begin to search require less time to find a vacant parking space than those who search in advance while approaching the destination out of fear that parking space is difficult to find.

Upon first examination, it is surprising that the model did not include parameters that refer to knowledge of the local parking conditions (frequency and trip length) or user preferences, but these impacts are actually covered by the parking search strategy. In addition, the model did not include the parking purpose because it can be related to the time when parking demand is realised, i.e., with parking utilisation level at that time.

6. CONCLUSION

In this paper, a model for forecasting parking search time was developed based on data gathered from face-to-face interviews of on-street parking users in the central Belgrade area. The model was tested using

standard statistics, which proved that the model is successful in fitting the observed data.

The adjusted model was used to identify the parameters that affect how long a user searches for a vacant parking space. The influence of the parking utilisation level was confirmed, and the influence of the parking search strategy was recognised. The significance of these results lies in a better understanding of the search process as well as in the definition of policies and measures applied to minimise these undesirable phenomena and its associated negative effects.

Parking search strategy is related to knowledge of the local parking conditions. Those users who do not know the local situation well begin to search for parking in advance while approaching the destination out of fear that a parking space will be difficult to find. To reduce the number of users who apply this strategy, users should become better informed of the vacant parking spaces. This process is usually performed by the introduction of the Parking Guidance Information System (PGI system).

In the case of the central area of Belgrade, the introduction of this system in off-street parking lots and parking garages would be pointless² because vacant parking spaces can be found anytime (without assistance from the PGI system) [19], whereas it may be useful for on-street parking.

Real-time information on the availability of on-street parking spaces can be obtained using electronic parking meters³. However, because of their disadvantages, parking meters are rarely used and are in the process of replacement by modern technologies for payment, and therefore, this method for gathering data is not viable.

Recently, real-time information has been generated from sensors placed at every parking space. However, users will still more often receive information on the probability of finding a vacant on-street parking space based on historical data on parking utilisation.

Although this information is not real-time, such information is better than no information. It should be noted that this system is limited to the conditions of high occupancy that exist in the central area of Belgrade.

²As long as tariff system is in use, which leads to under-utilised off-street parking lots and parking garages.

³This means that a restrictive parking regime is introduced in that zone, which is usually the case in central areas.

Therefore, the focus should be placed on the second parameter that influences parking search time: parking utilisation level. Parking measures (primarily the parking price) should be defined in a manner that will balance the parking supply and demand, i.e., provide the desired parking utilisation⁴ (see [20]).

In the case of the central area of Belgrade, in addition to general imbalance, a structurally specific imbalance is especially evident: overutilisation of on-street parking and underutilisation of off-street parking and parking garages (Section 1). The main reason for this situation is the current parking prices (on-street parking is several times cheaper). Therefore, a better defined parking tariff system would reduce the parking search time [21].

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⁴ In the cities of developed countries the desired parking utilisation is usually 0.85 [2]. Due to the state of parking in Belgrade, however, a value of 0.95 should be adopted.

REZIME

UTVRĐIVANJE PARAMETARA OD KOJIH ZAVISI VREME TRAŽENJA SLOBODNOG PARKING MESTA

Vožnja zbog traženja slobodnog parking mesta je dugi niz godina bila zanemarena tema. Danas je prepoznat njen uticaj na nastajanje saobraćajnih zagušenja, potrošnju goriva i porast zagađenja, te ona sve više dobija na aktuelnosti i značaju. U tom smislu, intenzivno se ispituju uzroci koji dovode do traženja parking mesta i parametri koji na njega utiču. U ovom radu su, na osnovu podataka prikupljenih u centralnoj zoni Beograda, ispitani parametri koji utiču na vreme traženja parking mesta. Operativna primena dobijenih zaključaka se ogleda u mogućnosti uticaja na identifikovane parametre, sa ciljem smanjenja vremena traženja parking mesta, i time pratećih negativnih posledica.

Ključne reči: vreme traženja parking mesta, iskorišćenje parking mesta, politike parkiranja

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The Organizational Aspects of Key Account Management in Postal Traffic

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The organizational aspect of key account management (KAM) with a focus on organizational structure and team building are one of the most interesting and most controversial parts of the modern marketing strategic and management solutions. Organization of KAM in the postal service requires organization focused on customers. Developed and presented KAM methodology for the postal service can be one of the best solutions that contribute to the successful future development and transformation of the postal sector.

Key words: marketing management, postal services, methodology, key account

1. INTRODUCTION

Nowadays, many companies are trying to maintain competitive advantage through development of modern Relationship marketing (RM) program and other programs which provide customer loyalty. Because of the specific characteristics of postal traffic and postal services, one of the recommended programs and strategies for maintaining and nurturing long-term profitable relationships with selected group of strategic customers/users of postal services is a modern marketing management strategy of KAM.

This paper presents a framework of developed modified multi-phase strategic model for key account management in the postal services "*PostAIM*" according to [1], with a focus on its organizational aspect of the function of maintaining a competitive advantage and long-term profitable relationship of both companies. The proposed model has not been exploited yet.

2. THE NEED TO MANAGE KEY ACCOUNT IN POSTAL SERVICES IN THE REPUBLIC OF SERBIA

Key account management in postal traffic represents a modern strategy and marketing management

approach that is based on building and nurturing long-term profitable relationships with strategically important customers in order to achieve mutual benefit for companies involved in this business relationship. Due to the prevailing competition in the market of communication and distribution of goods, many companies build stronger and closer relationships with key customers. However, many companies still do not sufficiently understand how to develop strategies for working with key customers and which tools have to be used in order to achieve and improve their competitiveness. Key account management assumes consideration of mutual interest both of customer company, and on the part of the seller company, as well as inter-organizational coordination at all levels, Table 1.

Table 1. Mutual key benefits of key account management in postal services/traffic

Key benefits for the vendor company in postal services	Key benefits for key customer
Long-term increase in profits and competitiveness	Better information about services and products
Joint appearance – joint bid	Increase of delivered value
Improved knowledge about customers	A better understanding of price and delivered value
Close relationship, a.k.a. "open book" relationship	Reduced cost
Better information about the competition	Better information on the benefits of using the services of the postal

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	company
Measurable level of achievement	Capacity to build individual customer profile
Association of business plan and strategies	Guaranteed execution of services in cases of limited resources
Creating custom solutions for key customers	Delivery of customized business solutions for specific problems

The primary objective of key account management is creating the mutual long-term benefits for related companies. According to the results of conducted research during the development of the model in the selected company of postal services, Post Office of Serbia, the public postal operator and leader in the postal services in the market of the Republic of Serbia, it is concluded that there is a need for key account management in the postal services because:

- Less than 5% of customers generate about 79% of revenue
- Competition develops modern strategy for key account management
- About 70% of total customer servicing cost generate customers who earn less than 20% of revenue
- There is a need for allocation of company's available resources
- Strategically important customers of postal services believe that single postal and other services intended for mass users do not constitute an adequate response to their needs, etc.

The power of the small number of major market participants is notably increasing. Well known Pareto principle, 80/20, can be applied in postal traffic. Namely, approximately 20% of participants achieve about 80% of total turnover in one branch, that is, the postal sector. They require special treatment.

In this balanced inter-organizational relationship value, key customers should not be identified with "big buyers" who, with planned management activities, can over time be converted into a group of potential key customers. Key customers are strategic partners with whom the success is achieved and shared. There cannot be many, neither that type of relationship can be determined in advance.

3. METODOLOGY OF KEY ACCOUNT MANAGEMENT IN POSTAL TRAFFIC

In accordance with the primary objective of this study and presented key research results, the proposed methodology for KAM in the postal services, whose function is to formulate the framework of the strategic model for key account management. **KAM model „PostAIM“** is the result of modeling and essentially

defines key account management as a single whole. It is designed on the basis of scientific knowledge on the management of key customers and "good practice" to be enforced widely, primarily with the postal service, as well as in other activities of service sector. This model is based on the fact that key account management is a multi-stage strategic management process.

In accordance with this methodology and based on [1] we present only the framework of developed model for KAM in postal services, named „**PostAIM**“ which is based on the application of the same. Framework of this model is presented through 3 key management processes: planning and analysis, implementation and monitoring, Figure 1.

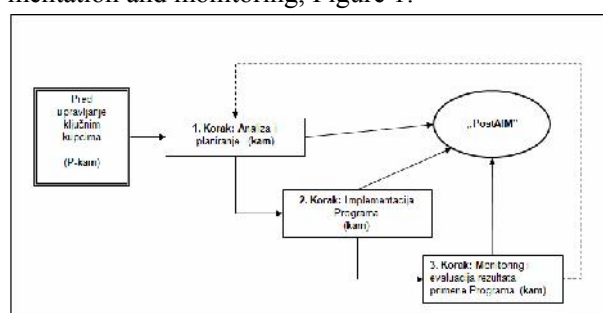


Figure 1 - Suggested framework of modified strategic multiphase management model of KAM in postal traffic "PostAIM" [1]

In addition to these three key management processes (analysis and planning, implementation and monitoring) that occur by the "step by step" system, the proposed methodology for key account management, based on a multiphase model of key account management, defines and conditions the progress of the following processes:

- adoption and management of ethical issues and norms of relations and possible conflicts,
- establishment and analysis of management accountability in the process of key account management, primarily based on developing and maintaining successful, profitable and lasting relationships with key customers, and
- establishment of accountability and the creation of management models for managing the cost and benefits in order to ensure achievement of optimum effects in the of key account management.

During the process of modeling „PostAIM“, another model of "customer value" has been developed, dubbed "**PostPPA**" which was used as a new approach for the realization of the process of identification, selection and categorization of key customers in the postal service, as one of the key processes of KAM, because its application is to determine which potential customers will obtain the status of key account, as

well as the strategies that will be applied based on the portfolio of key customers towards a certain categorie of customers.

KAM as a strategy represents an integral part of RM concept. This is also strategic approach used by companies to implement the principles of RM into their policy and strategy towards customers.

4. ORGANIZATIONAL ASPECT OF KEY ACCOUNT MANAGEMENT IN POSTAL TRAFFIC

The focus of this paper is the presentation of the organizational aspects of KAM in the postal traffic in order to adequately redesign the organizational structure as well as good positioning of the team for KAM, with the ultimate goal of providing one of the key requirements for the successful implementation of this strategy and defined goals, both with the program for KAM at the corporate level and with the defined objectives for each key customer. Whatever form of KAM organizational structure is chosen by the seller company, they have to provide both internal integration of key processes as well as its alignment with the processes of key customers.

Organizational changes in order to advance the implementation of the KAM are concerned with the structure and people. Organizational changes related to the structure, represent abandoning traditional division of labor and organization per functional areas and departments. Companies are organized so that all business functions and all employees are responsible for the customer. From the point of successful implementation of this concept, the companies that have many different customers need a lot of skill and wisdom to project an organizational structure that will support it. It is essential to form effective multifunctional teams to manage key accounts. Also, it is recommended to get rid of outdated products and services that are not a solution to problems that customers have and changing the organizational culture in order for the formed teams to be allowed to manage key customers with the possibility of full effect of the “locomotive” which they need to represent in the company. People that will be carefully chosen to be a part of multifunctional teams for KAM have to be professionals dedicated to this concept, as well as the success of both key customers and their company as a whole. This team should meet at least once a month, and more if necessary. The proposal of the framework structure, allocation of roles and contributions of individual members of a multifunctional team for key account management is presented in Table 2.

Tabela 2. Representation of composition, roles and contribution of individual team members in KAM in postal traffic

Composition and delegation of roles in the team for KAM	Contribution of team members
1. Head manager in KAM program for key account management (Director for key customers)	Planning, organizing, managing, monitoring and control of the program realization.
2. Head of key customers	Planning objectives for key customers, monitoring and implementation
3. Sales executive	Planning and implementation of key customers goals
4. Sales executive of postal services	Brings the knowledge and experience of the postal services in creating individual solutions for key customers
5. Sales executive of postal network	Brings knowledge and experience in terms of capacity and possibilities of postal network in creating solutions for key customers
6. Head of marketing	Coordinates marketing, promotion and development of research
7. Technical support -IT	IT support
9. Head of finance	Financial analysis, planning and control
10. Data controller	Obtaining all necessary internal and external data, detailed review of sales targets and plans

Only the cooperation of the team members can create a synergy that will function as efficiently and effectively in order to provide service to key customers. Finally, the management of relationships with key customers is done through a team responsible for managing key clients and who also works on developing an understanding of the company's needs so it can contribute to: generating high-value offers, identifying market opportunities, determining resources in line with growing demand and developing competitive advantages. Giving new tasks to existing retailers with a role in key account management, can be a kind of company's risk for a variety of attributes and skills that are needed for this sector. The most important of them are trust and integrity. Key element in key account management is the concept of value. One of the guaranteed ways to provide value for the customer is cost reduction that can provide increased internal efficiency. The focus of relationship marketing, on which the concept of key account management is based, is to ensure the long-term and profitable relationship for all parties in this business relationship. For this reason, this strategic issue in postal services in the Republic of Serbia should be given necessary attention. In the postal traffic, special care and diligence should be given to developing modified

business models that contribute to increasing revenues and reducing costs. Given the importance and role of PPO, it should be noted that the legal obligation of PPO is related to separate account management for reserved and non-reserved services. Directive of the European Parliament and of the Council dated in 1997 contains the manual for allocation of costs, which must be followed in preparation process of these financial reports. Under the provisions of the Directive issued in 1997, the said accounts must be verified and published publicly in accordance with the usual standards that apply to the commercial activities of a certain country [5]. This provides management, among other things, with a solid foundation for effective and efficient decision making.

Recent research have shown the necessity of integrating the activities of managers for key customers and brand managers in order to maximize mutual benefits for the company of postal services and a key customer company. Because of the specificity/uniqueness of postal traffic and postal services, we will present possible organizational solution on the example of a chosen postal services' company, Post of Serbia, PPO and a leader in the market of postal service in the RS, where important marketing management research for the development of these models has been performed, as well as the testing of such model, Figure 2.

ORGANIZATIONAL STRUCTURE ADJUSTMENT

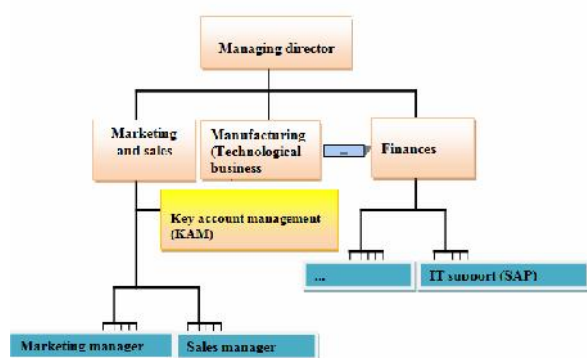


Figure 2 - Possible organizational positioning in traditional functional organization of postal traffic

Organizational positioning of team responsible for key account management has two dimensions:

1. Organizational level
2. Organizational unit/jurisdiction

Based on the results analysis of the conducted research related to the understanding and identification of the critical factors of key account management in the postal services in the Republic of Serbia, the proposed organizational solution has been presented. According to this, the corporate organizational di-

mension represents the organizational positioning of the team for key account management (KAM) in the business of Marketing and Sales, while the second dimension is concerned, the responsibilities of the same team include responsibility for managing key accounts for the organization as a whole, Figure 3.

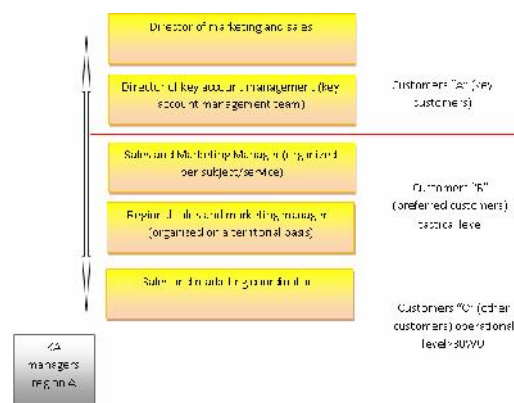


Figure 3 - Proposal of organizational adjustment of KAM in postal services in accordance with the categories of customers/buyers (on the Post of Serbia) [1].

In addition to the benefits that can be provided, the main drawback of this type of organizational positioning of KAM in the organization was that with one key customer, whose organizational units belong to different geographic regions, is being managed with more than one KA manager, whose activities often were not aligned. This method of positioning of KAM in organization gave more or less, the lowest effects of realistic potential [6].

It can be said that the KAM in the organization can organizationally be placed in different ways, from special internal strategic business unit, to the special division being determined according to the criteria of the product, geographical or combined principle [7].

When it comes to the external aspect of the KAM organization, in the context of the objective of the research and development model, has become "the postal service, a kind of organizing these activities could be the key buyers, Figure 4

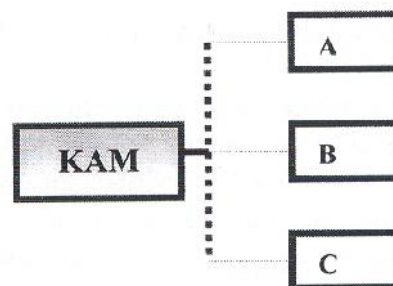


Figure 4 - KAM external organization according to key customers in postal services

This method of organization, as a support to the effectiveness of activities of KAM, focuses on existing key accounts. In this case it would be consistent with the objectives of key account management, postal services company could opt for a strategy of development for each customer, by accepting a set of tasks for the growth of selected strategically important customers and work on opening and strengthening the relations and operations in new areas, which could be defined in cooperation with other parts of the organization. In terms of organizational roles and responsibilities, the level of management responsibility for managing key accounts should be emphasized, which can be presented in terms of the following three key levels of responsibility:

- top management,
- director for key customers, and
- managers for key customers.

The results of the survey conducted during 2008 and 2009, suggest that one of the critical factors of KAM success are role and responsibility of top management, Figure 5.

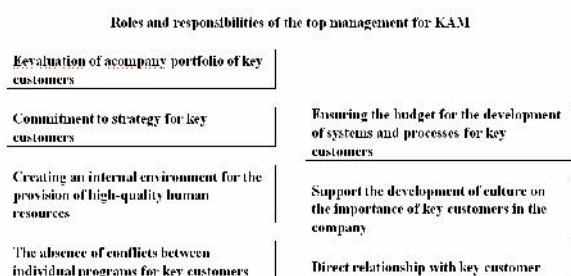


Figure 5 - Roles and responsibilities of top management menadžmenta in KAM [2]

The role of top management is extremely important to focus on key account management. If there is no real support and commitment of top management, and support to creating the sense of the importance of key account in the organization, the success of the same can be seriously called into question because its development requires a significant investment of company resources across the entire organization, and often reengineering of a large number of processes, and the acquisition of new knowledge by the management of a company. Key account managers are expected to be flexible, intelligent, stable, open to buyers, strong communication skills, able to avoid conflicts. Manager roles in KAM are numerous and responsible, given that the role and importance of key customers for one company is immense. However, their two main roles they can still be distinguished: [8]

Implementation: This means that they need to decide what will happen with the customer and work towards the safe realization of planned development.

Implementation requires a peculiar strategy and plans that rely deeply on understanding of customers, in order to be seen as part of effective implementation.

Promotion/advancement: It includes the development of relations [1], which will enable the implementation of business strategy. Relationships are the key point of contact with the customer, and require relations with other functions of customer, cross-functional relationships within the seller company, as well as possible relationships with external associations.

Above all, they must have a sincere desire to be “lawyers and consultants” to key customers of the seller company. The role and responsibility of managers for key customers is to develop and nurture successful long-term relationships with key customers because their role and importance is dominant in improving overall business performance and strengthening the competitive differential advantage, Figure 6.

Roles and responsibilities of key account managers

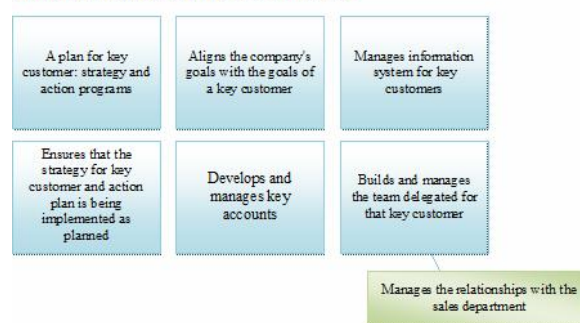


Figure 6 - Roles and responsibilities of managers for key customers, according to [2]

Based on these reasons, it is concluded that the key account management is one of the key roles and responsibilities of modern companies, primarily management.

Strategy for key account management in postal services, can only be effective when it comes to inter-organizational alignment of requirements and expectations of key customers and the organization of postal services.

5. CONCLUSION

Companies of postal services must quickly and effectively adapt their businesses to challenges in business environment by transforming the challenges into opportunities for their own growth and development.

Harmonization and coordination of a large number of different activities in companies providing the postal service due to the specific nature of postal is becoming more complicated which requires, among other things, a change [3] of focus and successful

implementation of modern business multi-functional business concepts and strategies with a focus on the customer/buyers, instead of its own products and services in the postal traffic, and the implementation of adequate essential radical and deep organizational changes expressed primarily through changes in organization structure, process structure, organizational culture and people. One of the directions of future successful development of postal services is definitely development of modern multidimensional strategy and marketing management approach to key account management.

In this paper, the organizational aspect of this modern strategy and key role and responsibility of the management has been presented as one of the critical factors of success.

It was concluded that the organization of key account management in the postal service requires an organization focused on customers providing integration of company resources located in different organizational units of the company with the purpose of servicing key customers. The success of modern multidimensional strategy and marketing management approach is directly related to the level of strategic commitment and approval of a company as a whole.

It should be emphasized that the presented methodology which is based on the application of "Post-AIM" and "PostPPA" models for key account management in the postal service is applicable to the postal service as well as other service industries.

Only the most profitable customers can justify the involvement of company resources in the develop-

ment of long term synergistic relationship partnerships.

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REZIME

ORGANIZACIONI ASPEKT UPRAVLJANJA KLJUČNIM KUPCIMA U POŠTANSKOM SAOBRAĆAJU

Organizacioni aspekt upravljanja ključnim kupcima (UKK) sa fokusom na organizacionu strukturu i izgradnju tima jedan su od najinteresantnijih i najkontroverznijih delova ove savremene strategije i marketing menadžment pristupa, zbog mogućih različitosti organizacionih rešenja. Organizacija UKK u poštanskom saobraćaju zahteva organizaciju fokusiranu na kupce. Predstavljena metodologija za UKK u poštanskom saobraćaju može biti jedno od dobrih rešenja koje doprinosi uspešnom razvoju poštanskog sektora u budućnosti.

Ključne reči: *marketing menadžment, poštanske usluge, metodologija, ključni kupci*

Multi-criteria Approach in Selecting Organization Model for Railway Transport of Montenegro PLC in Restructuring Process

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The process of creation of the railway market in Europe incited a change of an organizational structure of the previously monopolistic railway company that included both rail transport and infrastructure management operations. Regulation of relations within the transport operations in the rail transport market represents an important issue. The development and choice of a market-oriented organisation model is a complex process that includes government institutions and managing bodies of a railway company. This work uses a FAHP approach as decision-making support tested at the example of Railway Transport of Montenegro PLC.

Key words: restructuring, railway, organization design, FAHP

1. INTRODUCTION

In order to face the challenge of a dramatic fall of the railway's share in the transport market, the European Union (EU) decided on 1991 to help the railway get out of the multi-decade crisis through its Directive 91/440 EEC. Creation of operators' competition for the railway infrastructure, which would bring about an increase of service competitiveness – was a logical answer. The first step toward creation of a railway market was the creation of institutional prerequisites for changes and separation of infrastructure management and traffic operations on the one side from the passenger and freight transport on the other. These two operations used to be run within single company. This step represented the main condition for new operators to appear on the railway infrastructure.

The separation of operations into two separate companies represents a very complex multi-phase process with different target organisation models. The European experience so far proves it, among other things, since almost every country has applied by now a specific separation process and organisational model structure. However, three basic organisation models can be generated:

- a model of an “integrated” company with separate sub-accounts of infrastructure manager and transport operations;
- a holding company model
- a “separation” model or separation of the aforementioned operations into two completely independent companies.

The issue of organisation of passenger and freight transport operations of railway undertakings created after the restructuring of monopolistic state-owned companies has become very important in our time mainly due to the fact that the non-market organisation model is one of the main reasons for the situation in which the railway companies have found themselves.

The choice of an organization model is a crucial and the most difficult question in this process both for the state as the owner and for their company. For every government of the countries that are accessing the EU the development and choice of an organization model of their railways is one of the complex problems that must be solved. This work elaborates the issue of the choice of the organization model for the Railway transport of Montenegro PLC (ŽPCG) with the use of the fuzzy AHP approach.

The work has the following concept: after the Introduction, a development of the organization model is presented, with an emphasis on key requests of the relevant EU directives. The third chapter is dedicated to the multi-criteria approach proposed for the el-

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borated problem. The following chapter defines the relevant criteria while the next chapter gives definitions of the relevant criteria. The last chapter presents the conclusions of the work.

2. DEVELOPMENT OF ORGANIZATION MODEL

The development of the organization model starts with the existing organization and capacity of the system, i.e. its limitations and possibilities in terms of organizational changes. This way the target organization model is determined, which always requests realization in phases.

The key requests from EU directives on railway restructuring, the Government of Montenegro and the line ministries, as well as the requests originating from and reflecting the existing organisation system of ŽPCG and its railway market position are, in short, the following:

- the organization must allow a complete cost control for separate service types (freight transport, long-distance and local passenger transport);
- the managers must be authorised to cut the costs of services for which they are responsible in terms of their market competitiveness and quality, but also to bring decisions based on the commercial instead of technical aspect;
- the organization must support the management's focus on profitability and commercial improvements of business segments explained in the first paragraph here, as well as on the development of management in the spirit of entrepreneurship;
- the organization model must meet the guidelines for restructuring of European railways (transport policy and EU directives);
- the organization model must take into account the economic power of the country and the Government's guidelines on privatisation of public systems in Montenegro;
- the organization model must be compatible with those in the region and with the achieved level of restructuring in the neighbourhood;

Two basic organization models are developed and defined in the following manner:

- a model of mixed holding company ŽPCG;
- a model of disintegrated organizational structure of ŽPCG with vertically split (completely independent) companies.

Both models are developed only for the case of a clear determination of the owner and the management of the company for the changes in the spirit of the EU directives in this field and a support for the state's processes of EU integration. The first model is characterized by a gradual restructuring, while the second one represents a clear orientation toward privatization

as the basic concept or restructuring of the railway in Montenegro. Each of the two basic models are further developed into three sub-variants. The first variant includes an organization structure through three independent companies (freight transport, passenger transport and rolling stock maintenance). The second and third variants define two companies, freight transport and passenger transport while the second variant foresees the maintenance function in both companies and in the third variant it is assigned to the passenger transport.

3. MULTICRITERIA SELECTION AS SUPPORT IN DECISION-MAKING PROCESS

Today, ŽPCG is a public limited company with mixed capital structure in which the state and its funds hold 90% while four privatisation funds and citizens hold 10% of shares. Its strategic decisions, such as the one on the company's organization model, are brought by the Shareholders Assembly in which the State has majority part. However, since the representatives of the capital are attending the Assembly meetings, the decisions of this type are always adopted at the premises of the "real" owner (the Government of Montenegro) and those with a dominant influence on its decisions. This is why one of the basic problems is to identify the real decision makers and find an informal model of decision making allowing functioning of the key players.

Considered from another point of view, there are many representatives of the state-owned capital shares with different interests, criteria and preferences. The Government itself has different requests and criteria by its economic segment, ministries responsible for finances and transport, on the one side, and the members of the Board of Directors and the company management on the other. The presence of multiple players in the process of selection of the optimal organization model for ŽPCG indicates existence of different interests and criteria by which each of them is guided.

There is no doubt that different players have different inclination toward different models. The issue is further complicated by the fact that the most of the selection criteria for organisation model are not easily quantified. Therefore, the decision making in selecting the optimal model organization has the following characteristics:

- there are several models of railway company organization;
- there are several criteria for decision making;
- the decision making involves several persons with different levels of importance;
- there are conflicts between criteria;
- the criteria are of unequal importance;

- the importance of certain criteria as well as the very preference of the decision makers regarding those criteria change in time;
- the values of some criteria can only be descriptively expressed.

Obviously, this is a typical multi-criteria analysis task that also involves ranking for decision making purpose. There is a series of methods of multi-criteria decision making that could be used in cases like this. From a user – decision maker's point of view, what determines the choosing of the right multi-criteria method is the complexity of the usage and the understandability of the method. The choice of an adequate method of the multi-criteria decision making is completely determined by the characteristics of the problem itself, the level of its complexity and the experience of the user during the application of different methods.

The analytic Hierarchy Process – AHP is a method of multi-criteria analysis and decision making characterized by the analysis of scenarios and decision making through a consistent evaluation of hierarchies that include: goals, criteria, sub-criteria and alternatives. The method belongs to the field of multi-criteria decision making with conflicting goals while evaluation of possible decisions is implemented in the atmosphere of compromise. That principle of AHP allows the search for the compromise (the best possible) instead of the optimal solution, since there is no one in this type of problems. Therefore, this method has been chosen as a support for the decision making on the selection of the organization model for ŽPCG in its restructuring.

The essence of the AHP approach is comparison every criterion with every else, and then comparison of all the alternatives among each other for every criterion. According to the previously described AHP approach, what needs to be done is to define the parameters of the problem and to determine the types of the generalized criteria with the necessary meter for every criterion. Relations between the elements of the system used for the consideration of uncertainty and imprecision during the generation of the matrix of comparison between different criteria and alternatives are expressed through fuzzy numbers. The application of the basic fuzzy arithmetic from fuzzy matrixes of comparison of elements of the system results in fuzzy weights of criteria and alternatives. After that a defuzzification brings about discrete values of weights of criteria and alternatives.

4. DECISION MAKING CRITERIA

At generating the criteria (as well as at generating the organization model) the following was heard in mind: that the criteria respect the existing reality of

ŽPCG; primarily the financial situation, ability and knowledge of the management and other employees, possibilities of the State as the owner of the ŽPCG and its institutions regarding their commitment to the requests of the restructuring of the ŽPCG and change of the organization model; influence of ŽPCG's environment reflected in Montenegro's wish to speed up its EU accession as well as its commitments from the Stabilisation and Association Agreement, EU requests regarding the organization model expressed through its directives, the state of the process of restructuring of railway companies in the region.

In determining the criteria experiences of other railway managements were taken into consideration as well as theoretic knowledge on the necessity to follow certain performances of the system. The previous knowledge resulted in the following criteria for evaluation of certain alternatives, i.e. the suggested organization models:

- effectiveness and efficiency of the organization (X_1);
- requests of EU directives (X_2);
- capability to adapt to changes (X_3);
- openness for privatisation (X_4);
- staff rightsizing (X_5);
- possibility to implement the model (X_6).

The „effectiveness and efficiency of the organization“ means effectiveness and efficiency of the proposed organization model in terms of its manageability, functioning and use of all sorts of resources, primarily the human resources and means. It is a criterion with linear preference and is evaluated according to the Satty's scale, as do all the other criteria.

The second criterion „requests of EU directives“ means the extent to which the EU directives' recommendations are met. The directives and other EU documents have a projection to form a unique railway market on the entire European territory as a geographic space, which means a clear separation between the infrastructure managers and operators which would allow transparency in competition. And finally, the process of restructuring lead towards separation of operations of freight and passenger transport. In these conditions certain models can be assessed according to their position in terms of being a step forward or “sideward” toward the process of establishing the passenger and freight transport market.

The third criterion „capability to adapt to changes” indicates the organization's capability to change and adapt to the changes, whether they are requested by the market, EU or the owner. The tendency is to model the organization in a way that would make capable to adapt.

The fourth criterion „openness to privatisation“ indicates the assessment of the fitness of the model for the entrance of private capital into the company.

The Government of Montenegro has chosen to privatize a part of the public sector¹ including ŽPCG, as a way to improve its services and respond to the need to restructure it. This impose the necessity during the generation of the model to make sure that everything that is not the core business should be privatized as soon as possible and then allow the private capital to enter the parts of the company running the core business for which it would show interest.

The fifth criterion „staff rightsizing“ means the assessment of the number of employees according to the given organization model and whether that number leads toward staff rightsizing since the staff in this moment seem to be much oversized. The assessment in accordance with this criterion is an estimate by the decision makers whether the model, more or less, leads toward the staff downsizing.

The sixth criterion „possibility to implement the model“ means the how strongly the model is established in the real framework of the environment and the current situation of the company. „Real framework of the environment“ means the current and future capacities of the environment in terms of the support for the model. It includes the assessment of the capacity of the competent state institutions requested for the implementation of the model, of the interested political players and their balance of powers, dynamics of changes in the neighbourhood, possibility of financial support by the state, etc.

Under „current condition of the company“ it is meant all level of the management's capability to perform changes requested by the given model, possibility to bring new managers, the speed at which the existing management would be capable to adopt the changes, as well as the support of the trade union and the employees.

5. SELECTION OF ORGANIZATION MODEL FOR RAILWAY TRANSPORT OF MONTENEGRO

By applying the fuzzy AHP approach, weights of the considered criteria (Table 1) are achieved as well as the final values of the defined alternatives (Table 2). The coefficient α represents the degree of reliability of the decision maker, while the coefficient λ is the index of optimism of the decision maker.

Picture 1. Shows the definite ranking of alternatives according to which the alternative A₆, or the future organization model of Railway Transport of Montenegro PLC is made of two independent shareholders companies: Freight Transport PLC and Passenger Transport PLC, with the function of rolling stock maintenance being assigned to Passenger Transport

PLC, has priority over other alternatives. For this variant a definition (design) of a micro-organisation is needed.

Table 1. Total weight of considered criteria

Criteria	Total weight		
	Left	Middle	Right
X1	0.1101	0.3208	0.8637
X2	0.0609	0.1829	0.5244
X3	0.0219	0.0419	0.1337
X4	0.0422	0.1393	0.4164
X5	0.0301	0.0703	0.2159
X6	0.0917	0.2448	0.6477

Table 2. Final results after application of fuzzy AHP

$\alpha = 0.5$			Discrete values		Normalized values	
			$\lambda=0.5$	$\lambda=0.7$		
(1)	(2)	(3)	(4)	(5)	(6)	(7)
A ₁	0.0820	0.5152	0.2986	0.3852	0.1411	0.1411
A ₂	0.0565	0.3459	0.2012	0.2590	0.0951	0.0949
A ₃	0.0375	0.2277	0.1326	0.1706	0.0627	0.0625
A ₄	0.1284	0.8537	0.4911	0.6361	0.2321	0.2330
A ₅	0.1180	0.7511	0.4345	0.5612	0.2054	0.2055
A ₆	0.1569	0.9584	0.5576	0.7179	0.2636	0.2630
		Sum	2.1156	2.7301	1.0000	1.0000

Sign	Definition
A ₆	Organization structure made by two independent public limited companies: Freight Transport PLC, Passenger Transport PLC, while the function of rolling stock maintenance is assigned to Passenger Transport PLC.
A ₄	Organization structure made by three independent public limited companies: Freight Transport PLC, Passenger Transport PLC, Maintenance of Rolling Stock PLC
A ₅	Organization structure made of two independent public limited companies: Freight Transport PLC, Passenger Transport PLC, while the function of rolling stock maintenance is organized within both companies.
A ₁	Mixed holding company made of three companies: Freight Transport ltd, Passenger Transport ltd, Rolling Stock Maintenance ltd.
A ₂	Mixed holding company made of two companies: Freight Transport ltd, Passenger Transport ltd, and the function of rolling stock maintenance is assigned to Passenger Transport ltd.
A ₃	Mixed holding company made of two companies: Freight Transport ltd, Passenger Transport ltd, while the function of rolling stock maintenance is organized within both companies.

Picture 1 – Composite rankings of alternatives

¹ „Decision on Privatisation Plan for 2012, Government of Montenegro, 2012“

6. CONCLUDING CONSIDERATIONS

This work is developing a model for the choice of the organizational structure of the railway company. The choice of the company structure is a very complex issue within the process of restructuring of a railway company. The authors recommend a fuzzy AHP approach for the solution of the problem concerned. The developed model has been applied to the case of Railway Transport of Montenegro PLC.

According to this variant, Railway Transport of Montenegro would be transformed into two shareholders companies for freight and passenger transport, while the passenger transport would include the rolling stock maintenance as well.

The main reasons for this variant are the following:

- In our surrounding, the best chance for success of the process of restructuring that has already started has the freight transport company.
- It is estimated that, due to the current situation of the freight and passenger transport, the privatisation of rolling stock maintenance would fail, i.e. there would not be interested buyers under the current circumstances.
- In the given circumstances of necessary subventions for the passenger transport a problem of sustainability of the function of maintenance as a separate company would arise for the state as the majority owner, and it would be an aggravating circumstance. Under such conditions, a simple solution would be to merge the operation of passenger transport and maintenance within a single company with one management and a far stronger subordination and control.
- Limited human resources would be concentrated and the management function would be simpler for the state.
- The common functions would be merged and thus be less costly both for maintenance and passenger transport.

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REZIME

VIŠEKRITERIJUMSKI PRISTUP KOD IZBORA MODELA ORGANIZACIJE „ŽELJEZNIČKOG PREVOZA CRNE GORE“ A.D. U PROCESU RESTRUKTURIRANJA

Proces stvaranja željezničkog tržišta u Evropi uslovio je i promjenu organizacione strukture dosadašnjeg monopolističkog željezničkog preduzeća koje je objedinjavalo djelatnosti transporta i upravljanja infrastrukturom. Uređenje odnosa u samoj djelatnosti transporta na željezničkom transportnom tržištu predstavlja važno pitanje. Razvoj i izbor organizacionog modela okrenutog tržištu predstavlja složen proces koji uključuje institucije vlade i upravljačke organe željezničkog preduzeća. U radu je korišćen FAHP pristup za podršku odlučivanju i testiran je na primjeru „Željeznčkog prevoza Crne Gore“ A.D.

Ključne riječi: restrukturiranje, željeznica, projektovanje organizacije FAH

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Building Materials Based on Fly Ash as Possible Solution for Reduction of Air Pollution Caused by Emissions from Power-plants

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Most frequent environmental pollution sources are emissions caused by technological processes taking place at power-plants. High production of fly ash, the main residue in coal combustion, represents extreme hazard for the environment. Air pollution is taking proportions that require special attention, thus certain regulations are being imposed. The goal of the legislation is to reduce harmful emissions into the atmosphere by imposing standards for air quality and maximum emissions from various sources. Besides regulations, option of reapplication of fly ash in building materials industry is another solution for on-going problem. Fly ash can be used as component in cement, mortar, concrete, bricks, tiles, asphalt. Using produced fly ash capacities is sustainable solution for saving natural resources and environmental protection, but also a basis for designing new building materials from recycled nusproducts.

Key words: fly ash, pollution, regulations, building materials

1. INTRODUCTION

Industrial revolution is one of the main reasons for increasing trend of air pollution which has been recorded in the previous three centuries. Air pollution, as the most hazardous pollution, implies presence of one or more undesirable solid, liquid or gaseous substance in the air which causes threats for human kind and natural surrounding.

The type of particles emission in industrial zones depends on the industry type and the fuel used in combustion process [1].

Coal is one of the most frequently used fuels in energy plants. Smoke and sulfur dioxide from burning coal can conjugate with fog producing so-called "industrial smog". In high concentrations smog can be extremely toxic, both for humans and other living organisms.

Regulated concentrations of the main urban pollutants are given in Table 1.

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The European Union attempts to harmonize ecological legislation throughout Europe and, thus, to ensure a high level of environmental quality, especially in member countries, but also for other European citizens in the parts of Europe and beyond the EU borders. Countries are required to adopt the legislation in the field of environment and complete its application within about 10 years of post-accession [2].

The Directive of the Council 96/62 EC in assessing and managing air quality is a general legislative framework in this area. The Directive has established a group of atmospheric pollutants, which are supposed to define specific standards on air quality, within special directives-sisters. This list includes CO₂, HO₂, particular particles, lead, ozone, cadmium, arsenic, nickel and mercury.

For areas where the actual level of any, one or more pollutants exceed the maximum value or limit of tolerance, obligation is to adopt and implement an action plan to achieve the maximum values in given time.

In Serbia, legislation norms for emission are being covered by the republic laws and regulations [3, 4].

For pollution prevention, as well as remediation of already polluted air, it is necessary to develop appropriate strategies which must include local, regional and global factors. These strategies include repair of electro-filters in power-plants, introduction of “pure” rather than “dirty” technologies, rational use of energy (thus reducing consumption of fossil fuels) and recycling of the waste materials obtained as nusproducts during technological processes.

Table 1. Main air pollutants in urban areas.

Type of pollution	Source of pollution	Concentration, $\mu\text{g}/\text{m}^3$
<i>Solid particles - ash</i>	Fuel combustion	0.04-0.4
Reducing of solar insolation and visibility, increasing cloudiness, appearance of fog. Possible lowering of the temperature of the Earth.		
<i>Sulphur dioxide</i>	Fuel combustion	0.5-1
Chronic disease of plants, reducing yields in agriculture, deforestation. Respiratory disease.		
<i>Nitrogen oxides</i>	Fuel combustion at high temperature	0.05-0.2
Absorption of sunlight, creation of photochemical fog-smog. Destruction of a number of materials, reducing yields, deforestation. Reducing the content of hemoglobin in the blood.		
<i>Carbon monoxide</i>	Incomplete combustion	1-50
Reducing the content of hemoglobin in the blood.		
<i>Soluble hydrocarbons</i>	Incomplete combustion	<3
Disease of plants with higher concentrations of $0.2 \mu\text{g}/\text{m}^3$. Exasperating effect on the eyes.		

Fly ash, originating from coal based power-plants, represents a huge ecological and financial contemporary problem. The generation of this by-product has already reached an alerting quantity of approximately 175 million tons per year [5]. Fly ash depots are constantly increasing in size. Fly ash production leads to the problems of disposal as well as environmental damage by causing air and water pollution on a large scale [6]. Namely, fly ash is regarded as a toxic material owing to its high concentration of leachable heavy metals and, in some cases, to the presence of various organic compounds. Thus, a significant risk to the environment threatens from the possible leaching of hazardous pollutants, such as toxic-metals [7, 8].

Disposal of the fly ash became an increasing economic and environmental burden. Finding disposal sites became increasingly more difficult. The environment is at constant and alerting risk of air, water and soil pollution, while the storage expenses, as well as

expenses of water and air refining are perpetually increasing. As the consequence, there is a growing interest in looking for applications where the fly ash can be used as a potential resource for preparation of products with high-value. As per the estimation, utilization of fly ash can be targeted to an extent of 40–50 % in various fields. World-wide, this waste is utilized primarily in cementitious products, but remainder is directly discharged into ponds or landfills. These numbers have urged researchers to look for new and alternative applications of produced fly ash [9].

Approximately 6 - 7 millions of tones per year of fly ash are being produced in Serbia whilst an insignificant amount of it is being reused in the construction industry and in mass-production, generally. At the beginning of the 21st century, measured amount of solid fly ash particles emission, in Serbian power-plants, was at least 10 times higher than minimal amount allowed by European Union ($50 \text{ mg}/\text{m}^3$). In certain thermal plants electro-filters produced gases with extremely high solid particles concentration: $1000 - 2000 \text{ mg}/\text{m}^3$. In year 2003, a project concerning innovation and restoration of electro-filters was introduced. The goal of the running project is to repair all electro-filters in Serbian thermal plants and to adjust their working-regime in accordance with allowed solid particles emission level [1].

Possible applications of fly ash can be grouped into following categories:

- construction materials - cement, concrete, ceramics, glass/glass-ceramics, light aerated concretes, building blocks, lime-silicate elements (gas-concrete);
- geotechnical applications - fly ash can be built in dams and embankments, used in road constructions, pavement, soil stabilization, protection of river banks, protection of plastic-clay soil layers, tailings and non-stable sand ground;
- other - fly ash can be used as filler in refractory concretes, for asphalt mixtures, for injection mixtures, as adsorbing material and for sludge conditioning [10].

Each application has own environmental impacts and benefits, but all of them are resulting in advantages in waste minimization. Application of fly ash in building industry is the only way to solve the ongoing global environmental problem.

2. EXPERIMENTAL

The properties of the fly ash are strongly dependent on its geological origin and the combustion process of the coal in energy plant. It is important to characterize fly ash in detail to ascertain its potential

uses as raw material in the production of high value products within industry of building materials.

The physico-chemical properties of the fly ash originating from three different coal-fired power plants are presented, evaluated and discussed in this work. The fly ash samples were named subsequently: EFP1, EFP2 and EFP3. Each sample originated from different power-plant. The fly ash samples were landfilled without any previous treatment and have not been mixed with household or similar type of waste

Chemical composition analysis of the fly ash samples was performed by means of X-ray fluorescence method (XRF spectrophotometer ED 2000 - Oxford). The loss of ignition (LOI) content was determined by the weight difference between room temperature and 1000 °C. The maximum temperature was held constant for 4 h.

Differential thermal analysis (DTA) of the fly ash samples was performed with a Shimadzu DTA – 50 apparatus. Approximately 30 mg of a sample, which was previously homogenized and then dried for 6 h at 105 °C, was used for a DTA testing along with α -Al₂O₃ (corundum) powder as reference sample. The sample was heated under an air atmosphere from 20 up to 1100 °C at heating rate of 10 °C/min.

Homogenized and dried (for 6 h at 105 °C) fly ash samples were analyzed by X-ray powder diffraction (XRD). XRD patterns of the fly ash samples were obtained using a Philips PW-1050 diffractometer with a graphite monochromator, NaI(Tl) detector and λ Cu –K α radiation and a step/time scan mode of 0.05 °/s.

The microstructure of the fly ash samples was characterized by scanning electron microscopy method (SEM) using a JEOL JSM-6390 Lv microscope. The original fly ash powder (without further grinding) was used as sample. The samples were covered with gold powder. SEM microphotographs were recorded at different magnifications: 100x, 1000x and 1500x.

Potential mobility of trace elements from the fly ash samples was determined by means of leaching test [11]. The leaching test was performed at a liquid/solid ratio of 10 L/kg with a stirring time of 24 h and deionized water as the leachant. The content of major and trace elements in the leachates were determined by means of inductively coupled plasma atomic emission spectrometer ICP-AES (Perkin-Elmer Optima 5300 DV).

The bulk density and the mechanical strength of the fly ash samples were determined in accordance with classic laboratory procedure which is analog to the procedure applied in cement samples investigation. Samples of cement-mortar with fly ash replacement factor 30 % were shaped into dimensions 40x40x160 mm and submitted to the testing. Pou-

zzolanic activity was estimated by mechanical characteristics determination method.

3. RESULTS

The chemical compositions of the fly ashes (EFP1-3) were mutually compared and correlated with standard European fly ash (EEFP) [12]. Results and comparison are given in Table 2.

The obtained experimental results for fly ashes EFP1-3 were similar to the certified composition given for EEFP. Thus, analysis of the main oxides in the EFP1-3 verifies possible usability of investigated fly ashes. As in the case of European fly ash, the investigated fly ashes consisted mainly of silica, alumina and iron oxides depending on the origin of a fly ash. Relatively low loss of ignition in weight (LOI) was attributed to the fact that organic matters were not present in the investigated fly ash samples. All three fly ash samples EFP1, EFP2 and EFP3 can be classified as alumo-silicate ashes. Therefore, all investigated fly ash samples show pouzzolanic behavior and can be used as substitution for bonding agent in concrete or mortar.

Table 2. Chemical composition of the fly ashes.

Constituents, weight %	EEFP	EFP1	EFP2	EFP3
SiO ₂	41.1–59.6	57.49	53.49	58.32
Al ₂ O ₃	17.6–35.6	17.72	21.28	18.08
Fe ₂ O ₃	2.6–16	10.48	6.2	6.85
TiO ₂	0.5–2.6	0.52	0.56	0.57
CaO	0.5–11.8	6.96	7.61	8.71
MgO	0.8–3.8	1.98	2.74	2.3
P ₂ O ₅	0.1–1.7	0.02	0.03	0.02
SO ₃	0.1–8.6	1.06	0.78	1.29
Na ₂ O	0.1–1.2	0.36	0.44	0.5
K ₂ O	0.4–4	0.59	1.21	1.16
CO ₂	0.6–7.6	0.09	0.25	0.11
LOI	1.1–8.1	2.94	4.91	1.84

Trace element concentrations of EFP1-3 are shown in Table 3. It was noted that EFP1-3 had lower concentrations of a number of trace elements, namely Pb, Cd, Zn, Hg, Ba and Se than European fly ashes. Even though trace elements are present as a relatively small fraction in fly ash, they are, nevertheless, investigated due to their tendency of cumulative build-up, long life and high toxicity to humans and environment in general. Relatively low level of mentioned trace elements, usually results in low leachability of toxic elements and heavy metals. Thus, there is equally low environmental risk posed by the presence of contaminant trace elements in the fly ash if it is used

in a construction element and exposed to the action of rain and air.

The leaching test provided information on the leaching potential of various chemical constituents appearing within investigated fly ash and fly ash based cement mortar (with 30 % replacement factor) in normal environment. The water leaching trial showed potential mobility of elements existing in the fly ash composition: Cr, Ni, Cu, Zn, As, Se, Cd, Sb, Ba and Pb. Results are given in Figure 1. Transition of the elements leached was close to or below the detection limit with water as leaching agent. After comparing results of leaching test for EFP1-3 and for fly ash based cement mortar, overall conclusion was that there is no significant difference in results and investigated fly ashes are secure for application in construction materials industry.

Table 3. Chemical analysis of trace elements.

Trace element, ppm	EEFP	EFP1	EFP2	EFP3
Pb	40-176	15.5	19.1	24.4
Cd	1-6	0.1	0.00	0.2
Zn	70-924	52.3	36.1	56.6
Cu	39-254	52.4	26	35.9
Ni	49-377	21.7	41.3	50.9
Cr	47-281	97.6	148.1	135.1
Hg	<0.01-1.4	0.00	0.00	0.00
As	22-162	10.6	9.9	132.2
Ba	311-3134	51.5	53.3	86.2
Sb	1-120	0.5	0.1	1.1
Se	3-30	1.8	1.7	1.4

Results of the mineralogical analysis of the fly ash are given in Figure 2. Clay components within fly ash contain coal particles and as result of its phase transformation on elevated temperatures, amorphous and crystalline phases were formed. These phases have different chemical compositions which, as well as phase ratio, influence fly ash final characteristics.

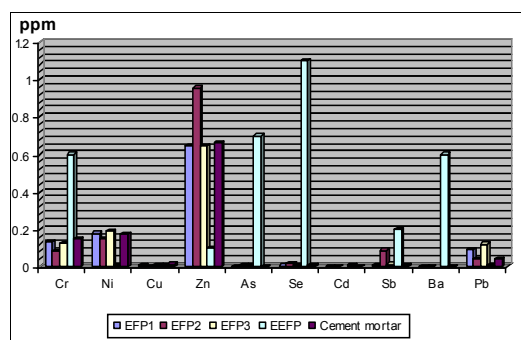


Figure 1 – Leachability of fly ash.

XRD diffractograms highlighted high amount of amorphous matter within all investigated fly ash samples. Some of the identified crystalline major phases present in the fly ash were aluminosilicate glass, quartz (SiO_2) and mullite ($\text{Al}_6\text{Si}_2\text{O}_{13}$). The only defined peaks on diffractograms relate to quartz. The background hump between 10 and 40° in the X-ray spectrum provided additional evidence of the presence of an amorphous phase. Calcite, magnetite, hematite, fluorite and anhydrite were noted in negligible amounts. The very few differences observed in the mineralogical composition might be attributed to the heterogeneity of the fly ash composition. Namely, it is possible that fly ash contacted and merged with some other matter originating either from air or ground while lying on a landfill. Sample EFP1 showed the lowest level of crystallinity and it was found to be one of the fly ashes with the highest amorphous material and lowest quartz and mullite contents, while the sample EFP3 had the most noticeable quartz peak on diffractograms, i.e. the highest level of crystallinity.

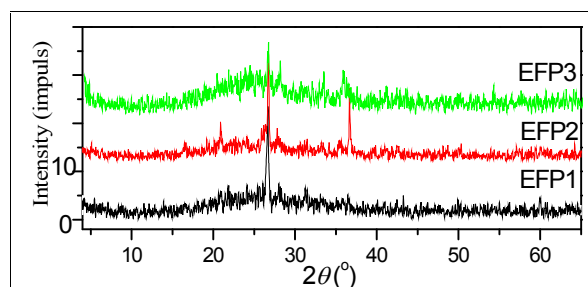


Figure 2 – XRD diffractogram of EFP1-3.

Processes taking place during fly ash thermal treatment were identified by means of DTA method. DTA curves are given in Figures 3. All DTA curves have a small peak at approximately 200°C which corresponds to the volatilization of the water mechanically bonded in form of H_2O molecule. Thus, the first dimensional change occurred between room temperature and 100°C and it was related to the loss of humidity. During temperature interval from 100 to 450°C hydration water was altogether lost. Peak showing at approximately 500°C is exothermic and characteristic for fly ash. Exothermic hump corresponds to the transformation of organic matter present in the fly ash samples and to the decomposition of CaCO_3 and the burning of residual coal present in the fly ash.

The second peak is endothermic and distinctly visible and located at approximately 900°C . This peak was induced by presence of alumo-silicates. The results of DT analysis led to the conclusion that investigated fly ashes were thermally stable at temperatures around 900°C and could be directly used in

processes carried out at or below this temperature, which means that they could be applied as component for high-temperature construction materials (thermo insulation mortar or refractory concrete). Differential thermal analysis also showed a certain change above 900 °C which pointed to the additional structural changes in fly ash occurring with further increasing of the temperature, i.e. initiation of the sintering process.

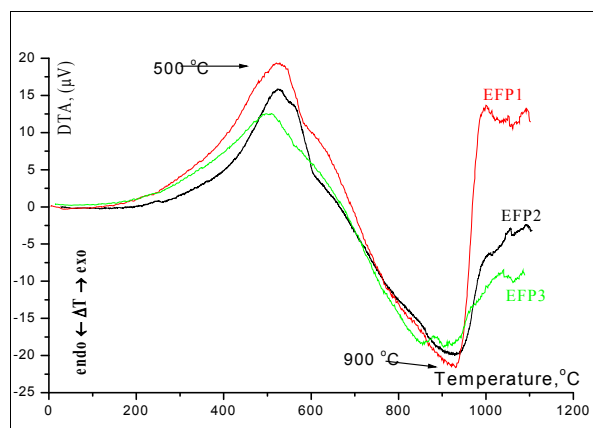


Figure 3 – DTA diagram of EFP1-3.

All of the fly ash samples studied revealed very similar particle size distribution. The small particle size of the fly ash is advantageous factor for obtaining better reactivity of the material in transformation processes, especially when it comes to fly ash „building-in“ into 3-dimensional structure of concrete and other cementitious materials. Average grain-size is 0.089, 0.118 and 0.143 mm for EFP1-3, respectively. Further milling would only improve characteristic of the fly ash.

Investigated mechanical characteristics of the fly ash samples are given in Table 4.

Table 4. Mechanical characteristics of the fly ash.

Mechanical characteristic	Bulk density,	Compressive	Flexural
Sample	g/cm ³	strength, MPa	strength, MPa
EFP1	2.18	4.50	1.50
EFP2	2.20	4.60	1.50
EFP3	2.17	7.70	2.20

The values of the bulk density are approximately same for all investigated fly ash samples. EFP3 sample has the highest compressive and flexural strength, which could be correlated to its intense crystallinity and better developed structure than the structure of EFP2 and EFP1.

In addition, pozzolanic activity was estimated and presented in Fig.4 As expected from chemical analysis, all investigated fly ashes have high pozzolanic activity. The highest value of pozzolanic activity was obtained for EFP3 sample. As previously concluded,

mechanical activation of fly ash would induce rise in both flexural and compressive strength, but also in pozzolanic activity. This phenomenon can be explained by increasing of the specific area of fly ash due to process of grinding and milling.

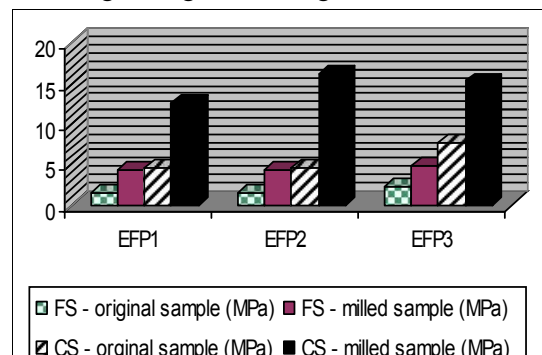


Figure 4 - Pozzolanic activity of fly ash samples: FS – flexural strength, CS – compressive strength.

Figures 5. and 6. show SEM microphotographs of some of investigated fly ashes recorded with different magnifications. As SEM microphotographs show, fly ash is a mixture of various grains of different size and shape, i.e. different inorganic phases and possibly certain quantity of unburned organic materials.

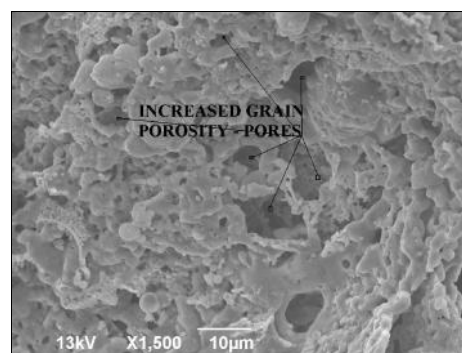


Figure 5 - SEM of EFP1 (magnification 1500 x).

Fly ash was mainly composed of spherical hollow particles. Increased superficial porosity of fly ash grain is evident. Visible pores are regularly shaped and round.

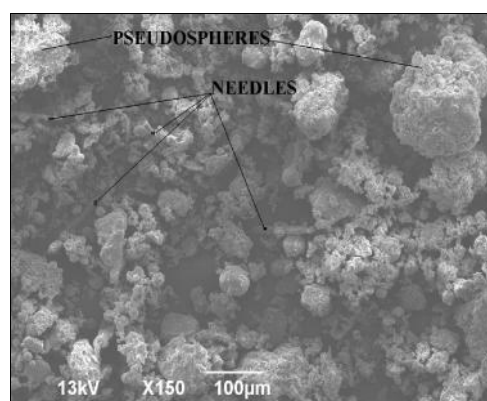


Figure 6 - SEM of EFP3 (magnification 150 x).

Other particles with different shape, size and texture were identified by SEM method. Namely, it can be seen that each fly ash sample is a composition of various grains of different sizes, shapes and morphology. Such diverse composition of fly ash is in relation with varieties in its chemical and mineralogical composition previously explained. Most of the grains in the mixture were spherical or rounded, although irregularly shaped grains were also present.

Irregularly shaped grains and agglomerations immersed in the fly ash mixtures. These irregular grains and agglomerations usually correspond to calcite (CaCO_3) which was identified with XRD method. Pseudospheres, i.e. spherical particles composed of various layers or grains were noted. Such particles usually correspond to the presence of magnetite. Specific needle-shaped particles are visible and they are either found isolated or merged with spheres in agglomerations. According to XRD analysis these needle-like shapes correspond to the mullite crystals. Quartz was also found as irregularly shaped particles.

Grain porosity was evidently present as it can be seen in Fig.5. Smaller, internal pores are, also, visible within superficial pores, which lead to the conclusion that the fly ash grains are intersected with pore channels which might increase water absorption. Extremely porous particles might correspond to unburned coal.

4. CONCLUSION

Air pollution originating from energy-plants threatens to damage environment, both visible and invisible parts of nature. The consequences affect the general climate, because destruction of vegetation reduces the possibility of restoration of oxygen. Pollution of air, as the basic condition of life, threatens human health and life, as well as the whole above-ground biocenosis (forests and plants).

Republic of Serbia in its process of integration into the family of the European Union must harmonize the regulations in the field of ecology. As it is necessary to harmonize the regulations it is also necessary to direct the population to develop awareness of the protection of the environment in which they live and necessity of reapplication of waste materials. It has already been common practice in the European Union, but in Serbia this is on-going procedure. The state must regulate, through the system of education, basic introduction into ecology, environment, human share in the pollution and the ways to prevent it all. Only the timely education and informing with consequences and the ways of their prevention can develop awareness.

Since the fly ash is potentially hazardous for living environment, it is necessary to recycle it and to find its reapplication instead of leaving it on open

landfills. Most economic manner of the fly ash recycling is its re-application in the industry of construction materials.

Investigation of the fly ashes showed that they have negligible level of organic impurities and potentially toxic and/or leachable elements. The investigated fly ashes, due to extent chemical analysis, were classified into aluminosilicate group, i.e. the group of ashes accompanied with well manifested pozzolanic/bonding properties which is of importance for fly ash application as cement component or substitution. Investigated fly ashes showed satisfying grain-size distribution and excellent physico-chemical, thermal and mechanical characteristic, with accent on significant compressive strength which is of huge importance for fly ash application as a substitution for small fraction aggregate in concrete or mortar. Because of its morphological properties and structural and thermal stability, fly ash could be used as additive or filler for thermal insulation materials, as well as refractory and other high-temperature building products.

The fly ash showed high pozzolanic activity which makes it useful as a raw material to make cement or cement replacement in concretes and mortars. Milling and even possible mechanical-activation of fly ash would result in further advance of characteristics.

On the negative side, SEM analysis pointed out on increased fly ash grain porosity which could cause higher water necessity during the preparation cementitious mixtures. Such thing can be avoided by application of water-reducing additives or admixtures.

Leaching test carried out on the fly ashes denied possibility of potential transition of toxic elements if fly-ash based building material is in contact with water. Thus ground or underground water contamination by migrating toxic fly ash constituents is also denied.

The fly ash properties determined in this work could be regarded as representative for most of coal fly ash produced in energy-plants. Thus, investigated fly ashes have excellent characteristics which opens new frontiers for its utilization, not only in the region but world-wide.

5. ACKNOWLEDGMENT

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SUMMARY

GRAĐEVINSKI MATERIJALI NA BAZI ELEKTROFILTERSKOG PEPELA KAO REŠENJE ZA SMANJENJE ZAGAĐENJA VAZDUHA PROUZROKOVANO EMISIJOM IZ TERMO-ELEKTRANA

Najčešći uzročnici zagađenja životne sredine su emisije uzrokovane različitim tehnološkim procesima koji se odvijaju u termoelekttranama. Velika produkcija elektrofilterskog pepela, koji je glavni ostatak pri sagorevanju uglja, predstavlja ogroman rizik i opasnost za životnu sredinu. Zagađenje vazduha je poprimilo tolike razmere da se ovom problemu obraća specijalna pažnja i sa tim u vezi uvode mnoge regulative. Cilj legislacije je da se smanji opasna emisija u atmosferu, a to se postiže uvođenjem standarda vezanih za kvalitet vazduha i maksimume emisije raznih zagađujućih čestica. Pored uvođenja regulative, moguće rešenje za problem zagađenja i njegovog smanjenja jeste reaplikacija letećeg pepela u industriji građevinskih materijala. Elektrofilterski pepeo se može upotrebiti kao komponenta pri proizvodnji cementa, maltera, betona, opeke, pločica, asfalta. Korišćenje elektrofilterskog pepela je održivo rešenje za očuvanje pripodnih resursa i zaštitu životne sredine, ali i osnova za dizajniranje novih građevinskih materijala na principu reciklaže nusprodukata.

Ključne reči: *leteći pepeo, zagađenje, regulative, građevinski materijali*

How to Build a Sustainable Model of Health Care with Disruptive Innovation

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There is a little dispute about the fact that we need to transform expensive, complicated products and services into ones that are higher in quality, lower in cost, and more conveniently accessible. This challenge is not unique to health care. Our intention is to provide a road map for those seeking innovation and reform – an accurate description of the terrain ahead, about which data are not yet available. Much of today's political dialogue on health-care reform centers on how to pay of the health care cost in the future. This road map offers the other half of the equation: how to innovate to reduce costs and improve the quality and accessibility of care. We don't simply ask how we can afford health care. We show how to make it affordable less costly and better quality. Most modern industries started where health care is today, with products and services that were expensive and complex, but were transformed toward improved quality, cost, and convenience through disruptive innovation. Disruptive transformations were rarely initiated by the leading companies in these industries. The reasons? At the outset the disruptive innovations could not meet the needs of industry leaders or their customers. And the profits from disruption were unattractive when viewed from the perspective of the dominant business model. Instead, disruptions have always taken root by first addressing the simplest problems of the least demanding customers. Disruptive technologies and business models have been the mechanisms that brought affordability, consistent quality, and convenient accessibility to most segments of our society. Disruption hasn't treated kindly the companies that have ignored it. But it has been good for mankind. In industry after industry disruption has made obsolete the trade-off that previously forced a choice between quality and affordability. It delivers both.

Key words: Innovation, disruptive technology, eHealth, privacy, standards, interoperability, quality

1. INTRODUCTION

All over the world in developing and developed countries' health care cost is a major problem for every government and societies itself. Serbia is 26th place in the world with Health care expenditure cost with 10.4% of GDP which represents highest in the region. (Croatia 7.8%, Albania 6.6%, Montenegro 9.1%, Israel 7.6%). With aging of population currently 16% of population are over 65 year old and unemployment rate of 26,6% question is sustainability of affordable Health care. Other factor that we presentment in this road map is that disruptive technologies and inno

vation can burst employment and overall economic growth. Serbia has a high potential in human resources and with restructure of current business model health care can become a leading industry.

Now passed 15 years since Clayton Christensen, professor of business administration at Harvard, introduced the term "disruptive technology into the lexicon of business management theory of disruptive innovation in his book, *The Innovator's Dilemma*, in 1997. The term have a very specific meaning: "disruption" is an innovation that makes things simpler and more affordable, and "technology" is a way of combining inputs and materials, components, information, labor, and energy into output of greater value. He postulated that consumers will seek out those who can do the jobs they want done and evaluate them by three simple measures: level of transparency, convenience of delivery, and cost that repr-

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esents value. Christensen argues that two conditions are necessary for disruptive innovation to increase to scale: (1) technological enablers (i.e., technologies that provide routine solutions to problems that previously required trial and experimentation); and (2) a disruptive business model that can profitably deliver these routine solutions to customers in affordable and convenient ways (6, 7).

Technological enablers of disruptive innovation in health care are: (1) advances in medical knowledge and more precise medical diagnostics and therapies (including drugs, devices, equipment, and procedures); and (2) advances in ICT, including Web 2.0 applications, broadband communications, and wireless integrated micro systems (WIMS).

If precision diagnosis is not available, treatment is determined by “intuitive medicine” (i.e., therapeutic problems solved by highly trained, expensive professionals through intuitive experimentation and pattern recognition). Intuitive medicine gives way to evidence – based medicine when a patient’s treatment is guided by data showing which therapeutic interventions are, on average, most effective.

Innovative, “disruptive” models of care delivery are opening the way to a new division of labor among health care providers and changes in the structure and location of care delivery. Eventually, they could cause transformation of the overall health care system by accelerating the development and application of ICT tools and techniques, with final improvement of health care quality as final result, together with cost reduction. With this eHealth blueprint we aim to solve the numerous problems of Serbian health system (21, 22).

2. BUILDING INFOSTRUCTURE

Central themes of Serbia’s eHealth Blueprint are connectivity, innovation and a commitment to improve patient care and care outcomes. Through these themes and through collaboration we will deliver Blueprint for Serbia’s Electronic Health Record. The Blueprint sets the architectural scope and context for eHealth and provides a framework for the implementation of Serbia’s Electronic Health Record (or EHR). Today, Serbia is either in non existence or mixture of health information systems; however, most are unable to communicate or share patient information with each other. The Blueprint seeks to improve that. The EHR’s goal is to have a well-managed, sustainable, and cost-effective eHealth network. It must also allow patient information to be safely and securely shared with the highest level of privacy.

Ultimately it must improve health care delivery and patient outcomes and reduce costs.

In support of that goal, the Blueprint will help Serbia’s health care community in the following ways:

- It provides an overarching framework for collaboration and communication among stakeholders participating in the evolution of the EHR;
- It acts as a “map” to assist in planning and delivery of the EHR;
- It supports a governance framework that will ensure high quality, successful delivery of the EHR to the country;
- It establishes a set of standard target architectures to be used by all participants;
- It identifies the foundational components necessary to allow longitudinal patient information to be shared across the continuum of care throughout the Country

The Blueprint is an asset that was created based on extensive work on architectural design and implementation through consultation with healthcare providers and delivery partners across the country since 1994 with ad-on evolution updated with current technology level (24, 25).

Let’s begin by examining the challenges of building a country’s Electronic Health Record. The health sector in Serbia is a complex and high transaction volume environment. As the Blueprint was being designed, the existing environment was examined and evaluated. The numbers running in the background bring to light the size and complexity of that environment. There are over 30.000 clinicians in Serbia working within a diverse set of organizations. They create a wealth of health related data residing mainly on local computer systems or in classical written forms. The data is not standardized or accessible on a country- wide basis. Patient information is not easily shared. In addition to these challenges of interoperability, the country also faces increased health care costs. These costs are arising from an aging population, which has high expectations of both the quality and accessibility of their health care.

While the central theme of the eHealth Blueprint is connectivity, at the heart of the Blueprint is a commitment to improve patient care. Information Technology transformation is the bridge for change in the health sector. Providing clinicians access to the right information at the right time can result in faster, more informed, cost effective patient care.

As a patient interfaces with the healthcare system, many episodic interactions occur. These multiple interactions may include specialists, hospitals, pharmacies and other healthcare organizations. The information that healthcare providers need is not always

readily available. Therefore delivering an EHR with a patient-centric Blueprint will be transformational. As mentioned earlier, the healthcare environment in Serbia is complex. There are more than 100.000 professionals and a multitude of health care organizations. Each may have its own computer system – but most are unable to communicate with each other because they are simply not connected. Delivering an EHR -- available across the country - will mean bridging the borders between institutions and providers.

As the applications necessary to create the EHR are built and deployed, eHealth Serbia will continue to recognize the need to be responsive to local mandates within the health care community. As these challenges were examined, there was careful observation of the gaps, which exist today. The connectivity necessary to achieve the EHR requires information to flow between various systems.

Based on the work on Serbia's Health Information System since 1994, and from the experience of other industries, it is understood that point-to-point connections are cost prohibitive, and too time consuming to implement.

To connect 30.000 clinicians in Serbia, using hundreds of systems, in a point-to-point fashion is simply not an option. Enabling connectivity requires integration. And that integration will benefit providers and patients, the health system overall and reduce point-to-point connections between systems.

Achieving this connectivity is critical. Until all these pieces of data can be connected, a complete view of the patient health record cannot be seen. And clinicians will not have the tools they need for the delivery of faster, more coordinated care.

Every day hundreds of thousands of people interact with the healthcare system. As people move through the system, they leave a bit of themselves behind. Here's our current reality: Every interaction with a doctor, a hospital, or simply a pharmacy creates data.

- There is limited consistency in how this information is being captured.
- Interactions and the information received may be similar but fragmented.

A consistent, standardized approach is required, regardless of the back-end systems providing this information. The Blueprint offers a pragmatic approach to this challenge using methods such as:

- data aggregation
- master indices
- country standards and
- common services for data access and presentation

The Blueprint establishes how this data will be brought together - not by connecting individual systems - but by creating a set of common services shared by all systems. As the Blueprint was being designed, a clear need for central registries and repositories that are timely and accurate was reinforced. The data in these must be available in a private and secure manner whenever it is accessed.

With the need identified for central registries and repositories, several important hurdles need to be overcome. To address these, the Blueprint establishes a number of principles to ensure transparency, consistency, accessibility, security, privacy and availability.

These hurdles are analogous to those faced by other industries. For example, advancements in the financial industry are, today, often taken for granted.

But achieving services like online banking, Interaction, or the ability to use a credit card anywhere in the world, was a difficult and slow process, taking many years to achieve. Data was not consistent from organization to organization. The industry had to create consistencies in order to interoperate. The banking industry also had to deal with the existence of legacy systems. But the biggest challenge the industry dealt with was that of security and privacy (1).

Our financial and health information are both considered highly personal, and must be well protected. Healthcare today is dealing with the same challenges other industries have faced previously. The good news is that their investment and experience can be leveraged to expedite health care's journey to automation and secure information sharing. As with other industries, there are foundational pillars that must be respected. In health care these pillars are:

- Connectivity and Integration
- Security
- Privacy
- And Governance

The Connectivity and Integration pillar is critical to enabling data to be shared seamlessly across the Country. This pillar led to the establishment of:

- Nationwide Standards
- a Service Oriented Architecture (or SOA)
- and the need for an Enterprise Service Bus, as key elements of the Blueprint.

The Security and Privacy pillars are inter-related. Security protections provide the means by which the privacy of individuals whose data is stored in or shared by the EHR is protected. Patients' privacy is respected and maintained through the implementation of privacy practices and security protections.

Specifically, mechanisms such as encryption, access control, management of consent directives and audit logging and alerting ensure that privacy is embedded in the primary design. These ensure that only authorized persons are permitted to access and use the Personal Health Information stored in or shared by the ER. The Governance pillar addresses how the Blueprint will be orchestrated.

For an inter-operable EHR to achieve maximum benefit, the country needs to ensure that access to the regional repositories and registries is highly available. It must also meet the demanding transaction volumes of Serbia. And all of this must be done in accordance with privacy standards and appropriate patient consent mechanisms.

To this end, the EHR must deliver on a number of requirements:

- It must be available to all authorized users at any location, 24/7/three hundred and sixty-five days a year
- The transfer of information must be timely to ensure clinicians have access to the most up to date information
- It must embed privacy controls into its design to ensure data is automatically protected at all times.
- The environment must support the highest standards for privacy and security of the data
- It will make use of “National grade” exchange hubs. These best in class systems have been proven in other industries - uch as the financial sector. These hubs will take advantage of eHealth Serbia’s high availability network
- It must enable business process transformation and ensure that the complex privacy requirements of this environment are addressed
- It needs to be scalable and robust enough to handle the hundreds of millions of healthcare transactions that occur across the country, and
- Its information must be accessible to all citizens of Serbia

This undertaking is about building scalable and robust systems that will offer access not only to the clinicians across the country, but also to the 7,5 million people who call Serbia home. The Blueprint’s approach is to foster an environment in which many partners can innovate and share their services. The country has numerous valuable assets and a great deal of talent, scattered across its health care institutions. The country needs to be able to evaluate these assets and ensure that - where appropriate - components of the Blueprint are filled by what currently exists.

Because the Blueprint acknowledges the myriad of valuable, existing systems, it does not call for a wholesale change in the environment. Many other in-

dustries have successfully used the same approach to solve similar problems. What appears as seamless integration of financial institutions does not mean that homogeneous systems exist in the background. Legacy systems are everywhere, and those legacy systems are here to stay. The Blueprint establishes more than just a conceptual design for the delivery of the EHR. It identifies how the agency will partner with stakeholders to create a federated system. It elaborates on components that must be in place, such as governance, to ensure that this will become a reality.

3. INNOVATION CHALLENGE

Therefore the Blueprint is not just an architectural, conceptual design; it’s also a delivery partnership model. It identifies that it is necessary to have partners, to leverage the tremendous talent available in this country. At the core this is not about re-inventing the wheel. It is about leveraging assets that presently exist and integrating and connecting the country. Only where there are gaps or “white space” that needs to be filled in, will new assets and capabilities be deployed.

The Blueprint vision of the future is “anytime, anywhere access to patient health records in accordance with privacy standards and with the consent of patients”. Achieving this vision will be a challenge. But one thing is certain: If success is to be attained, all of the country’s existing assets and skill sets must be leveraged. Everyone within the health care system will need to work together. In recognition of this fact, the Blueprint maps out a framework for collaboration and innovation at all levels. The Blueprint’s sets out a federated implementation model, which allows many parties to build at the same time. It identifies standard architectures that demonstrate how everything comes together and interoperates while protecting patients’ privacy. It builds privacy requirements and security controls into the architecture of systems and business practices to comply with privacy laws. It identifies standard architectures that demonstrate how everything comes together and interoperates.

It is an open platform for innovation, giving eHealth’s delivery partners and vendor community an opportunity to look at it and determine how they can best contribute. It assumes strong, carefully orchestrated partnerships for collaboration. These investments should:

- Reduce costs and redundancies;
- Accelerate the pace of both development and implementation and
- Improve speed and access to information.

To appreciate how this multi-layer network of systems will work; the following series of diagrams

illustrate integration at the highest level. This infrastructure will allow people to connect to applications and services provided at either the nation-

wide layer, or at one of the regional hubs. On the left side of the diagram, are the consumers of the system, the clinician community across the country.

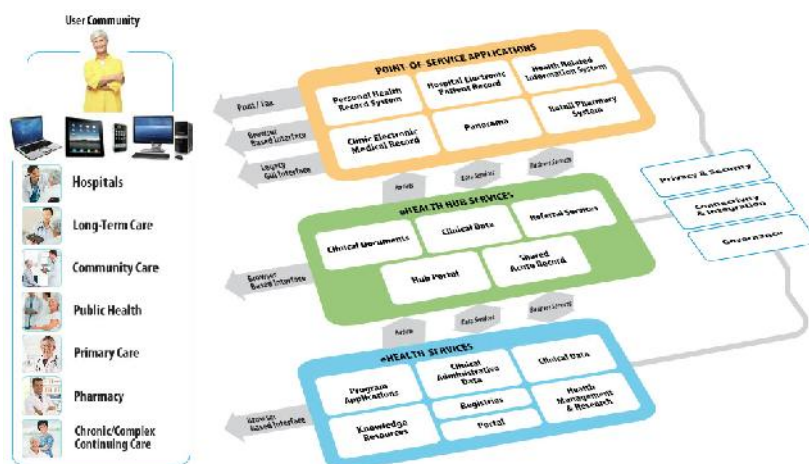


Figure 1 - Blueprint: multi-layer structure of eHealth system

4. LAYER'S

The first layer of the Blueprint (in orange) supports Point-of-Service Applications, such as a hospital's patient record systems, EMRs etc. The next layer (in green) provides for applications to be developed by regional hubs.

The third layer (in blue) is used for country nation wide applications implemented by eHealth Serbia itself.

All three layers adhere to consistent standards for privacy and security. A strong governance structure helps ensure alignment to the Blueprint, including consistent use of common services.

The common privacy and security services provide for one time authentication and ensures that the users only see information they have the right to view.

This streamlines access to applications, as users only need to make a single connection to access data. Although development takes place in parallel at the various layers, well-defined governance provides the discipline to help ensure that applications are implemented quickly without creating redundancy. The Blueprint identifies a set of common services that will be consistently used by the nation-wide layer and regional hub layer. Technology and processes are then put in place to ensure everyone can benefit from these common services.

The top layer includes point of service applications such as: Electronic Medical Records, hospital systems, Panorama for public health, and so on. Some of these are custom developed while others are commercially available. They may be heavily modified for the environments they support, but they are still a very key component of connectivity.

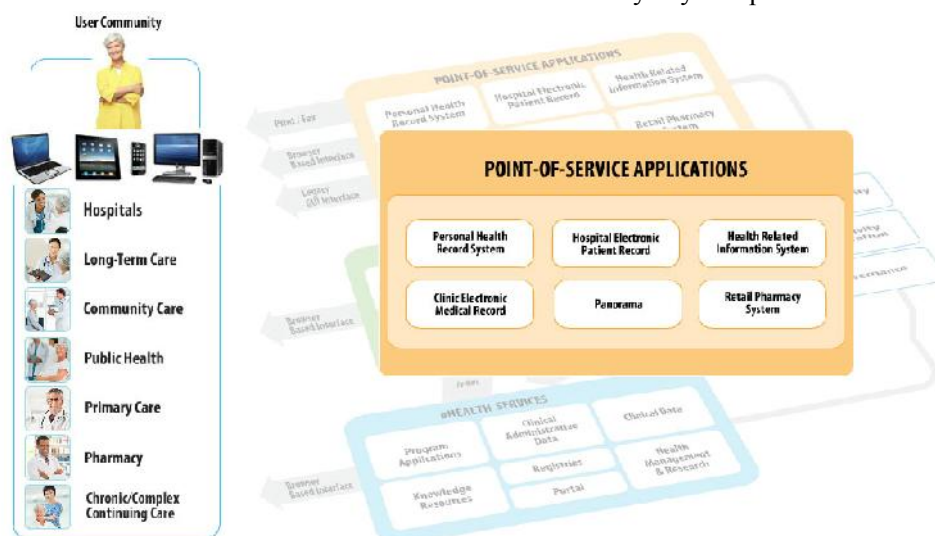


Figure 2 - Blueprint: point of services application layer

These “point-of-service” applications must be able to connect to the integration hubs and be able to expose the information within them.

The middle layer is a new layer that has been defined by the Blueprint and it's where the majority of innovation will take place.

This layer is where the magic happens. Here old systems will get renewed life. As was mentioned previously, it is important to leverage the work of the past to integrate where possible and only build new networks where necessary.

The middle layer creates the opportunity to make this a reality.

This layer is often referred to as the eHealth Hub Services and includes the Health Information Access Layer - the Enterprise Service Bus for Serbia – Cli-

nical Document/Data Repositories (or CDRs), regional portals and other capabilities. This layer of the Blueprint will be fulfilled by regional hubs, each developing applications for either their own geographic areas or even for country wide consumption.

Each regional hub has access to its own infrastructure that includes an eHealth-standard middle-ware layer with an Enterprise Service Bus.

The regional hubs can implement applications in parallel while adhering to the Blueprint principles and architectures. As strategic delivery partners, they also consume common services that apply across nation wide applications.

The infrastructure to support this layer of the Blueprint is the Health Information Access Layer and will be built in segments.

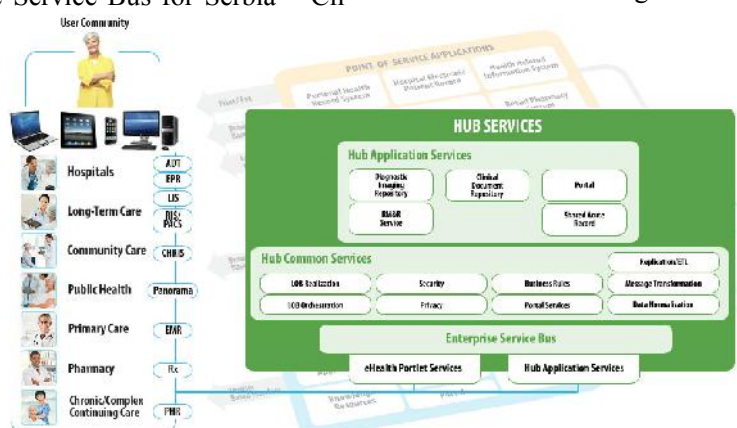


Figure 3 - Blueprint: Regional HUB services application layer

Together these hubs will create an integrated Health Information Access Layer across the country connecting clinicians, registries and repositories, and other health information data sources. As in banking, where your Interactive card allows you access anytime, anywhere with a secure and private connection - the Blueprint envisions similar connectivity for health care information.

There are many documents kept within the walls of hospitals to which the community needs access,

such as discharge summaries. It would take too long to build a central repository and align everyone.

It is more efficient and effective to deploy the CDRs in regions and allow the eHealth Hub Services Layer to provide this information where care happens.

The value in establishing these regional hubs is two-fold. First it fosters innovation and second it delegates responsibility to the people who are best able to provide it.

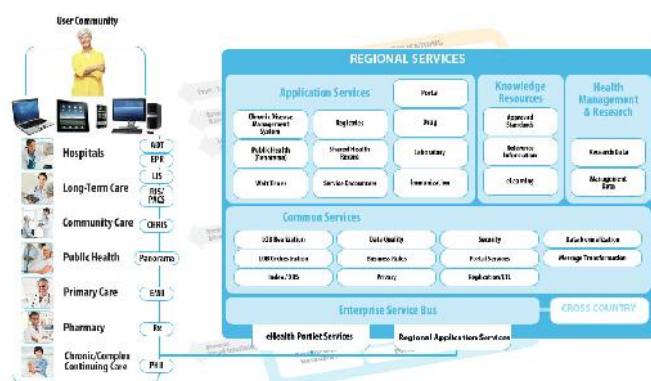


Figure 4 - Blueprint: Country wide medical application layer

5. STANDARDS AND CONCLUSIONS

The role that eHealth Serbia will play is to ensure that standards and interoperability are adhered to. Too much rigidity and centralization will stifle innovation - and that is not an option. As an example, there appears to be a plethora of portals across the country.

This Blueprint calls for the creation of primary and regional portals that have the same look, feel, and navigation, but different content. One of the portals will be national and will give access to nation wide information. Other portals are regional and provide the regions their gateway to the EHR.

The bottom layer includes the Nation wide registries, repositories, and other nation-wide capabilities.

For example, the Serbia Lab Information System (or SLIS) is the central repository for laboratory information for the country. It will be populated by both public and private laboratories.

The Enterprise Master Patient Index - or EMPI - provides a central place to uniquely identify each person. And a Consent Registry will allow individuals to control access to their information. The data contained within these repositories is maintained in accordance with privacy laws and best practices.

For many, the patient experience within the health care system can be best described as episodic. From a patient workflow perspective, 80 per cent of health care transactions begin with an initial visit to a

primary care facility within the community - either a family doctor or a local clinic. It then proceeds through a series of referrals to specialists, acute care facilities and other diagnostic centers for further tests and treatment, or to a pharmacy for prescription medication.

These referrals generally occur within defined geographic regions. Most of these acute care facilities have systems for information and discharge summary coding, and more often also have Electronic Health Record applications where richer information is kept for every patient.

The Blueprint allows portal solutions to pull data "on demand" from different connected facilities to create a consolidated view of a given patient's clinical profile. This leads to an act-on-demand paradigm for clinicians.

We are committed to embedding the Privacy by Design Principles advocated by the country's Information and Privacy Commissioner and has put in place nation wide privacy program. This will enhance and expand the organization's culture of privacy and set the stage to ensure stringent privacy practices on all components of the nation-wide EHR.

By creating an overarching, standardized set of security and privacy practices - innovation can then be safely accelerated as privacy and security have been embedded into the solution. The result is that user privacy is protected whenever data is shared by or stored within any component of the nation-wide HER

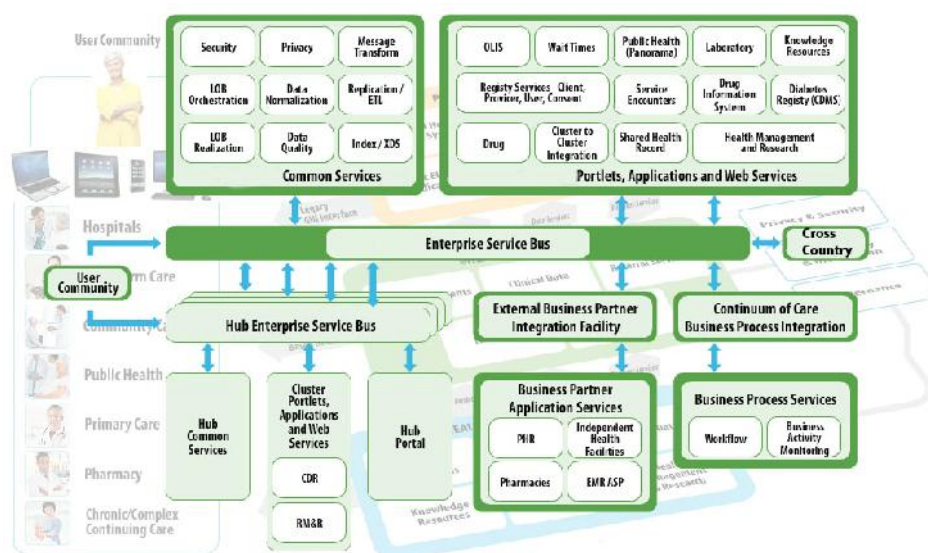


Figure 5 - Blueprint: Common services Governance application layer

Connectivity and integration are among the many components, which underscore the National EHR.

From our analysis of the successes and failures of eHealth initiatives in various jurisdictions around the

world, it is clear that well-established and effective governance are crucial to success.

eHealth Serbia must be committed to applying these learning's to the deployment of the provincial

EHR in Serbia by establishing a strong, effective and efficient governance program. We recognize that we must establish clear responsibilities to empower people, measurements to gauge effectiveness, control mechanisms to ensure compliance and deliver on commitment to keep all parties informed.

The listed references (1-28) can be used for more in-depth consideration of article topics.

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REZIME

KAKO IZGRADITI ODRŽIVI MODEL ZDRAVSTVENE ZAŠTITE JEDNOSTAVNIM INOVACIJAMA

Skoro da nema neslaganja o činjenici da nam je potrebna transformacija skupih, komplikovanih proizvoda i usluga u proizvode i usluge višeg kvaliteta, manje cene koštanja, jednostavane i dostupne korisnicima. Ovaj izazov nije prisutan samo u zdravstvenoj zaštiti. Naša namera je da obezbedimo putokaze onima koji traže inovacije i reforme - tačan opis predstojećeg puta, o kome još nemamo dovoljno podataka. Mnogi politički dijalozi o reformi zdravstvenih sistema fokusiraju se na to kako platiti troškove zdravstva u budućnosti. Ovaj vodič nudi drugu polovinu poluge za ravnotežu: kako napraviti inovacije da se redukuju troškovi i poveća kvalitet i dostupnost. Mi se ne pitamo kako priuštiti zdravstvenu uslugu. Mi pokazujemo kako da je priuštimo uz povećan kvalitet i manju cenu. Mnoge su moderne industrije počele tamo gde je zdravstvena zaštita danas, sa proizvodima i uslugama koje su složene i skupe, ali su se transformisale ka unapređenju kvaliteta, smanjenju cene i dostupnosti i prihvatljivosti korisnicima i to kroz disruptivne inovacije. Ove disruptivne inovacije su inicirane od vodećih industrijskih kompanija. Razlozi? Na početku disruptivne inovacije nisu ispunjavale potrebe lidera i korisnika. Zarada od ovih inovativnih promena nije bila atraktivna u poređenju sa zaradom vodećih poslovnih modela. Disruptivne promene su započinjale i puštale korenje, tako što su prvo rešavale najjednostavnije problem najmanje zahtevnih korisnika. Disruptivne tehnologije i poslovni modeli bile su mehanizam koji je doneo dostupan, konstantan kvalitet, i bio prihvatljiv za većinu stanovništva. Disruptivne tehnologije nisu bile blage prema kompanijama koje su ih ignorisale. Ali su bile dobre prema čovečanstvu. U industriji posle disruptivne inovacije nije više potrebno da se bira između kvaliteta i dostupnosti, kako je to bilo ranije. Disruptivna tehnologija nudi i kvalitet i dostupnost.

Ključne reči: inovacije, disruptivna tehnologija, eZdravlje, privatnost, standardi, interoperabilnost, kvalitet

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