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С А Д Р Ж А Ј

С О Д Е Р Ж А Н И Е

C O N T E N T S

ORDERED B-METRIC SPACES AND GERAGHTY TYPE CONTRACTIVE MAPPINGS

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Abstract:

The paper shows a new approach to proving the recent fixed point results in ordered b-metric as well as ordered metric spaces, established by several authors, with much shorter and nicer proofs. An example is given to illustrate our results.

Key words: fixed point, b-metric, comparable, well order, Geraghty mapping, b-Cauchy, b-complete.

Introduction and preliminaries

One of important generalizations of metric spaces are so-called *b*-metric spaces (type metric spaces by some authors). This concept was introduced by Bakhtin in 1989 and Czerwik in 1993.

Consistent with (Bakhtin, 1989, pp.26-37) and (Czerwik, 1993, pp.5-11), the following definition and results will be needed in the sequel.

Definition 1.1. (Bakhtin, 1989), (Czerwik, 1993) Let X be a (nonempty) set and $s \geq 1$ be a given real number. A function $d : X \times X \to [0,+\infty)$ is a *b*-metric if and only if, for all $x, y, z \in X$, the following conditions are satisfied:

(b_1) $d(x, y) = 0$ if and only if $x = y$,

(b_2) $d(x, y) = d(y, x)$,

(b_3) $d(x, z) \leq s(d(x, y) + d(y, z))$.

The pair (X, d) is called a *b*-etric space.

It should be noted that the class of *b*-metric spaces is effectively larger than that of metric spaces, since a *b*-metric is a metric when $s = 1$. The following example shows that, in general, a *b*-metric does not necessarily need to be a metric, see also (Aghajani, et al, 2014), (Abbas, et al, 2016, pp.1413-1429), (Ansari, et al, 2016), (Ding, et al, 2016, pp.151-164), (Djukić, et al, 2011), (Huang, et al, 2015a, pp.808-815), (Huaping, et al, 2015), (Huang, et al, 2015b, pp.800-807), (Hussain, et al, 2012), (Hussain, et al, 2013), (Jleli, et al, 2012, pp.175-192), (Jovanović, et al, 2010), (Kadelburg, et al, 2015, pp.57-67), (Khamsi, Hussain, 2010, pp.3123-3129), (Parvaneh, et al, 2013), (Roshan, et al, 2015), (Roshan, et al, 2014, pp.229-245), (Zabihi, Razani, 2014).

Example 1.1. *Let (X, d) be a metric space, and $\rho(x, y) = (d(x, y))^p$, $p > 1$ is a real number. Then ρ is a b-metric with $s = 2^{p-1}$, but ρ is not a metric on X.*

Otherwise, for more concepts such as *b*-convergence, *b*-completeness, *b*-Cauchy sequence and *b*-closed set in *b*-metric spaces, we refer the reader to (Aghajani, et al, 2014, pp.941-960), (Abbas, et al, 2016, pp.1413-1429), (Ansari, et al, 2016), (Djukić, et al, 2011), (Huang, et al, 2015a, pp.808-815), (Huaping, et al, 2015), (Huang, et al, 2015b, pp.800-807), (Hussain, et al, 2012), (Hussain, et al, 2013), (Jleli, et al, 2012, pp.175-192), (Jovanović, et al, 2010), (Kadelburg, et al, 2015, pp.57-67), (Khamsi, Hussain, 2010, pp.3123-3129), (Parvaneh, et al,

2013), (Roshan, et al, 2015), (Roshan, et al, 2014, pp.229-245), (Zabihi, Razani, 2014) and the references mentioned therein. Also, for the concepts such as partial order, comparable, well ordered, nondecreasing, increasing, dominated, dominating and other, we refer the reader to (Aghajani, et al, 2014, pp.941-960), (Abbas, et al, 2016, pp.1413-1429), (Ansari, et al, 2016).

The following three lemmas are very significant in the theory of a fixed point in the framework of metric and *b*-metric spaces. Also, we use these in the proof of our main results.

Lemma 1.2. (Aghajani, et al, 2014, pp.941-960, Lemma 2.1) Let (X,d) be a b-metric space with $s \geq 1,$ and suppose that $\{x_n\}$ and $\{y_n\}$ are b-convergent to x, y respectively, then we have

$$\frac{1}{s^2} d(x,y) \leq \underline{\lim}_{n\to\infty} d(x_n, y_n) \leq \overline{\lim}_{n\to\infty} d(x_n, y_n) \leq s^2 d(x,y). \tag{1.1}$$

In particular, if $x = y,$ then we have $\lim_{n\to\infty} d(x_n, y_n) = 0.$ Moreover, for each $z \in X$ we have

$$\frac{1}{s} d(x,z) \leq \underline{\lim}_{n\to\infty} d(x_n, z) \leq \overline{\lim}_{n\to\infty} d(x_n, z) \leq s d(x,z). \tag{1.2}$$

Lemma 1.3. (Jovanović, et al, 2010, Lemma 3.1) Let $\{y_n\}$ be a sequence in a b-metric space (X,d) with $s \geq 1,$ such that

$$d(y_n, y_{n+1}) \leq \lambda d(y_{n-1}, y_n) \tag{1.3}$$

for some $\lambda \in [0, \frac{1}{s}),$ and each $n = 1,2,...$ Then $\{y_n\}$ is a b-Cauchy sequence in a b-metric space $(X,d).$

Lemma 1.4. (Radenović, et al, 2012, pp.625-645, Lemma 2.1), (Jleli, et al, 2012, pp.175-192, Lemma 2.1) Let (X,d) be a metric space and let $\{y_n\}$ be a sequence in X such that $d(y_n, y_{n+1})$ is nonincreasing and that

$$\lim_{n\to\infty} d(y_n, y_{n+1}) = 0. \tag{1.4}$$

If $\{y_{2n}\}$ is not a Cauchy sequence, then there exist an $\varepsilon > 0$ and two sequences $\{m_k\}$ and $\{n_k\}$ of positive integers such that the following four sequences tend to ε^+ when $k \to \infty$:

$$d(y_{2m_k}, y_{2n_k}), d(y_{2m_k}, y_{2n_k+1}), d(y_{2m_k-1}, y_{2n_k}), d(y_{2m_k-1}, y_{2n_k+1}).$$

Main results

Let Ψ be the family of all nondecreasing functions $\psi:[0,+\infty)\to[0,+\infty)$ such that $\lim_{n\to\infty}\psi^n(t)=0$ for all $t>0$. If $\psi\in\Psi$, then $\psi(t)<t$ for all $t>0$ and $\psi(0)=0$.

Our first result is the following:

Theorem 2.1. *Let $(X,\preceq)$ be a partially ordered set and there exists a b-metric d on X such that (X,d) is a b-complete b-metric space. Suppose $s>1$ and $f:X\to X$ is an increasing mapping with respect to $\preceq$ such that there exists an element $x_0\in X$ with $x_0 \,°\, fx_0$. Assume that*

$$s\cdot\frac{1+sd(x,y)}{1+\frac{1}{2}d(x,fx)}\cdot d(fx,fy)\le\psi(M(x,y))+L\cdot N(x,y) \tag{2.1}$$

for all comparable elements $x,y\in X$, where $L\ge 0$,

$$M(x,y)=\max\left\{d(x,y),\frac{d(x,fx)\cdot d(y,fy)}{1+d(fx,fy)}\right\}$$

and

$$N(x,y)=\min\{d(x,fx),d(x,fy),d(y,fx),d(y,fy)\}.$$

If

(1) f is continuous, or

(2) whenever $\{x_n\}$ is a nondecreasing sequence in X such that $x_n\to u\in X$, one has $x_n\preceq u$ for all $n\in N$,

then f has a fixed point. Moreover, the set of fixed points of f is well ordered if and only if f has one and only one fixed point.

Proof. Suppose that $x_n\ne x_{n+1}$ for all $n=0,1,2,...,$ where $x_{n+1}=fx_n=f^nx_0$. In this case, we have $x_n\prec x_{n+1}$ for all $n=0,1,2,..$ Therefore, putting $x=x_n, y=x_{n+1}$ in (2.1) we shall prove that

$$d(x_{n+1},x_{n+2})\prec\frac{1}{s}d(x_n,x_{n+1}) \tag{2.2}$$

for all $n=0,1,2,....$ Indeed, then (2.1) becomes

$$s\frac{1+sd(x_n,x_{n+1})}{1+\frac{1}{2}d(x_n,x_{n+1})}d(x_{n+1},x_{n+2})$$

$$\leq \psi\left(\max\left\{d(x_n,x_{n+1}),\frac{d(x_n,x_{n+1})d(x_{n+1},x_{n+2})}{1+d(x_{n+1},x_{n+2})}\right\}\right)$$

$$+L\min\{d(x_n,x_{n+1}),d(x_n,x_{n+2}),d(x_{n+1},x_{n+1}),d(x_{n+1},x_{n+2})\}.$$

Since, $1<\frac{1+sd(x_n,x_{n+1})}{1+\frac{1}{2}d(x_n,x_{n+1})},\frac{d(x_n,x_{n+1})d(x_{n+1},x_{n+2})}{1+d(x_{n+1},x_{n+2})}<d(x_n,x_{n+1})$ and $d(x_{n+1},x_{n+1})=0,$ we have $s\cdot d(x_{n+1},x_{n+2})\leq\psi(d(x_n,x_{n+1}))<d(x_n,x_{n+1}).$ Hence, (2.2) follows.

Further, using (2.2), we have

$$d(f^2x_n,f^2x_{n+1})<\frac{1}{s}d(fx_n,fx_{n+1})<\frac{1}{s^2}d(x_n,x_{n+1}).$$

As $\frac{1}{s^2}\in[0,\frac{1}{s}),$ therefore by using Lemma 1.4, the sequence $\{f^2x_n\}_{n=0}^{+\infty}=\{x_2,x_3,...\}$ is a *b*-Cauchy sequence. This further implies that the sequence $\{fx_n\}_{n=0}^{+\infty}=\{x_1,x_2,...\}$ is a *b*-Cauchy sequence. Since (X,d) is *b*-Complete, $\{x_n\}$ *b*-converges to a point $u\in X.$

(1) First, we suppose that f is continuous. Therefore, we have

$$u=\lim_{n\to\infty}x_{n+1}=\lim_{n\to\infty}fx_n=f(\lim_{n\to\infty}x_n)=fu,$$

that is, u is a fixed point of $f.$

(2) Further, consider (2) of theorem holds. Using the assumption of $(X,d,\preceq),$ we have $x_n\preceq u.$ Now, we show that $fu=u.$ Firstly, we have

$$\frac{1}{s}d(u,fu)\leq d(u,x_{n+1})+d(fx_n,fu).$$

Now, using the assumption $x_n\preceq u$ and inequality (2.1), we have

$$\frac{1}{s}d(u,fu)\leq d(u,x_{n+1})+\frac{1+\frac{1}{2}d(x_n,x_{n+1})}{s(1+sd(x_n,u))}\cdot M(x_n,u)$$

$$+\frac{1+\frac{1}{2}d(x_n,x_{n+1})}{s(1+sd(x_n,u))}\cdot L\cdot N(x_n,u).$$

Since $M(x_n,u)\to 0$ and $N(x_n,u)\to 0$ as $n\to\infty$, the result follows, i.e., $fu=u$.

From Theorem 2.1, we have the following result which is an improvement from the corresponding results (Theorems 2.7 and 2.8) of (Ansari, et al, 2016).

Corollary 2.1. Let $(X,\preceq)$ be a partially ordered set and there exists a b-metric d on X such that (X,d) is a b-complete b-metric space. Suppose $s>1$ and $f:X\to X$ is an increasing mapping with respect to $\preceq$ such that there exists an element $x_0\in X$ with $x_0\preceq fx_0$. Assume that

$$\frac{1+sd(x,y)}{1+\frac{1}{2}d(x,fx)}\cdot d(fx,fy)\le \beta(d(x,y))\cdot M(x,y)+L\cdot N(x,y) \tag{2.3}$$

for all comparable elements $x,y\in X$,

where $L\ge 0$, $\beta:[0,+\infty)\to[0,\frac{1}{s})$ *with* $\beta(t_n)\to\frac{1}{s}$ *implies* $t_n\to 0$,

$$M(x,y)=\max\left\{d(x,y),\frac{d(x,fx)\cdot d(y,fy)}{1+d(fx,fy)}\right\}$$

and

$$N(x,y)=\min\{d(x,fx),d(x,fy),d(y,fx),d(y,fy)\}.$$

If

(1) f *is continuous, or*

(2) whenever $\{x_n\}$ *is a nondecreasing sequence in* X *such that* $x_n\to u\in X$, *one has* $x_n\preceq u$ *for all* $n\in N$,

then f has a fixed point. Moreover, the set of fixed points of f is well ordered if and only if f has one and only one fixed point.

Proof. Since $\beta(d(x,y))<\frac{1}{s}$, the condition (2.3) implies

$$s \cdot \frac{1+sd(x,y)}{1+\frac{1}{2}d(x,fx)} \cdot d(fx,fy) \le M(x,y) + L_1 \cdot N(x,y), \tag{2.4}$$

where $L_1 = s \cdot L.$ On the similar lines of Theorem 2.1, we have the result.

On the similar lines of Theorem 2.1, we have the following result.

Theorem 2.2. *Let $(X, \preceq)$ be a partially ordered set and suppose that there exists a b-metric d on X such that (X,d) is a b-complete b-metric space (with parameter $s>1$). Let $f: X \to X$ be an increasing mapping with respect to $\preceq$ such that there exists an element $x_0 \in X$ with $x_0 \preceq fx_0$. Suppose that*

$$s \cdot d(fx,fy) \le \beta(d(x,y))M(x,y) + L \cdot N(x,y), \tag{2.5}$$

for all comparable elements $x, y \in X$,

where $L \ge 0$, $\beta: [0,+\infty) \to [0,\frac{1}{s})$ with $\beta(t_n) \to \frac{1}{s}$ implies $t_n \to 0$,

$$M(x,y) = \max\left\{d(x,y), \frac{d(x,fx)\cdot d(y,fy)}{1+d(fx,fy)}\right\}$$

and

$$N(x,y) = \min\{d(x,fx), d(x,fy), d(y,fx), d(y,fy)\}.$$

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then f has a fixed point. Moreover, the set of fixed points of f is well ordered if and only if f has one and only one fixed point.

Proof. The condition (2.5) implies

$$d(fx,fy) \le \frac{1}{s^2} \cdot M(x,y) + L_1 \cdot N(x,y), \tag{2.6}$$

for all comparable elements $x, y \in X$, where $L_1 = \frac{L}{s} \ge 0.$ The rest of the proof is similar to Theorem 2.1.

Remark 2.1. *Since the proofs of the main results in (Ansari, et al, 2016*), (Zabihi, Razani, 2014) *are strongly dependent of Lemma 1.2 of Aghajani et al.* (Aghajani, et al, 2014, pp.941-960)*, it is too complex to deal*

with them. Our approach in Theorems 2.1-2.2, as well as in Corollary 2.1 covers all the results of (Aghajani, et al, 2014, pp.941-960) *without utilizing the lemma mentioned above. It is clear that our proofs are much shorter and nicer.*

Also, it is not hard to see that the main results in (Abbas, et al, 2016, pp.1413-1429) have much shorter proofs by the application of our approach, that is, without using Lemma 1.2 of (Aghajani, et al, 2014, pp.941-960).

In the sequel, we consider all three results in the case where $s=1,$ that is, (X,d) is a standard metric space. Here we have to use Lemma 1.4 to obtain our results.

Theorem 2.3. Let $(X,\preceq)$ be a partially ordered set and suppose that there exists a metric d on X such that (X,d) is a complete metric space. Suppose $f:X\to X$ is an increasing mapping with respect to $\preceq$ such that there exists an element $x_0\in X$ with $x_0\preceq fx_0$. Assume that

$$\frac{1+d(x,y)}{1+\frac{1}{2}d(x,fx)}\cdot d(fx,fy)\le \psi(M(x,y))+L\cdot N(x,y) \tag{2.7}$$

for all comparable elements $x,y\in X,$ *where* $L\ge 0,$

$$M(x,y)=\max\left\{d(x,y),\frac{d(x,fx)\cdot d(y,fy)}{1+d(fx,fy)}\right\}$$

and

$$N(x,y)=\min\{d(x,fx),d(x,fy),d(y,fx),d(y,fy)\}.$$

If

(1) f *is continuous, or*

(2) whenever $r\{x_n\}$ *is a nondecreasing sequence in* X *such that* $x_n\to u\in X,$ *one has* $x_n\preceq u$ *for all* $n\in N,$

then f *has a fixed point. Moreover, the set of fixed points of* f *is well ordered if and only if* f *has one and only one fixed point.*

Proof. First we suppose that $x_n\ne x_{n+1}$ for all $n=0,1,2,...$ Then, by taking $x=x_n, y=x_{n+1}$ in (2.7), we get

$$\frac{1+d(x_n,x_{n+1})}{1+\frac{1}{2}d(x_n,x_{n+1})}\cdot d(x_{n+1},x_{n+2})\le \psi(M(x_n,x_{n+1}))+L\cdot N(x_n,x_{n+1}),$$

where

$$M(x_n,x_{n+1})=\max\left\{d(x_n,x_{n+1}),\frac{d(x_n,x_{n+1})\cdot d(x_{n+1},x_{n+2})}{1+d(x_{n+1},x_{n+2})}\right\}=d(x_n,x_{n+1}),$$

because $\frac{d(x_{n+1},x_{n+2})}{1+d(x_{n+1},x_{n+2})}<1,$ and

$$N(x_n,x_{n+1})=\min\{d(x_n,x_{n+1}),d(x_n,x_{n+2}),d(x_{n+1},x_{n+1}),d(x_{n+1},x_{n+2})\}=0.$$

Since

$$\frac{1+d(x_n,x_{n+1})}{1+\frac{1}{2}d(x_n,x_{n+1})}>1,\psi(M(x_n,x_{n+1}))<d(x_n,x_{n+1}) \text{ and } N(x_n,x_{n+1}) \quad (2.8)$$

becomes $d(x_{n+1},x_{n+2})<d(x_n,x_{n+1}),$

i.e., $d(x_n,x_{n+1})$ is a decreasing sequence. Therefore, there exists $r\ge 0$ such that $\lim_{n\to\infty} d(x_n,x_{n+1})=r$. Assume that $r>0$, from (2.8), we have

$$\frac{1+r}{1+\frac{1}{2}r}\cdot r\le r \Leftrightarrow \frac{1}{2}r\le 0,$$

which is a contradiction. Hence $\lim_{n\to\infty} d(x_n,x_{n+1})=0.$

Now, we suppose that the sequence $\{x_n\}$ is not a Cauchy sequence in a metric space (X,d). By putting $x=x_{m(k)}, y=x_{n(k)}$ in (2.7), we obtain

$$\frac{1+d(x_{m(k)},x_{n(k)})}{1+\frac{1}{2}d(x_{m(k)},x_{m(k)+1})}\cdot d(x_{m(k)+1},x_{n(k)+1})\le \psi(M(x_{m(k)},x_{n(k)}))+L\cdot N(x_{m(k)},x_{n(k)}), \quad (2.9)$$

where

$$M(x_{m(k)},x_{n(k)})$$
$$=\max\left\{d(x_{m(k)},x_{m(k)+1}),\frac{d(x_{m(k)},x_{m(k)+1})\cdot d(x_{n(k)},x_{n(k)+1})}{1+d(x_{m(k)+1},x_{n(k)+1})}\right\},$$

and

$$N(x_{m(k)},x_{n(k)})$$

$$= \min\{d(x_{m(k)}, x_{m(k)+1}), d(x_{m(k)}, x_{n(k)+1}), d(x_{n(k)}, x_{m(k)+1}), d(x_{n(k)}, x_{n(k)+1})\}.$$

Now, letting to the limit in (2.9), as $k \to \infty$, and using Lemma 1.4, we get

$$\frac{1+\varepsilon}{1+\frac{1}{2}\varepsilon} \cdot \varepsilon \le \psi(\varepsilon) + L \cdot 0 < \varepsilon \Leftrightarrow \frac{1}{2}\varepsilon \le 0,$$

which is a contradiction. Hence the sequence $\{x_n\}$ is a Cauchy sequence. The rest of the proof is the same as in Theorem 2.1.

Corollary 2.2. Let $(X, \preceq)$ *be a partially ordered set and suppose there exists a metric* d *on* X *such that* (X, d) is *a complete metric space. Suppose* $f : X \to X$ *is an increasing mapping with respect to* $\preceq$ *such that there exists an element* $x_0 \in X$ *with* $x_0 \preceq fx_0$. *Assume that*

$$\frac{1+d(x,y)}{1+\frac{1}{2}d(x,fx)} \cdot d(fx, fy) \le \beta(d(x,y)) \cdot M(x,y) + L \cdot N(x,y) \tag{2.10}$$

for all comparable elements $x, y \in X$,

where $L \ge 0, \beta : [0, +\infty) \to [0,1)$ with $\beta(t_n) \to 1^-$ implies $t_n \to 0$,

$$M(x,y) = \max\left\{d(x,y), \frac{d(x,fx) \cdot d(y,fy)}{1+d(fx,fy)}\right\}$$

and

$$N(x,y) = \min\{d(x,fx), d(x,fy), d(y,fx), d(y,fy)\}.$$

If

(1) f *is continuous, or*

(2) whenever $\{x_n\}$ *is a nondecreasing sequence in* X *such that* $x_n \to u \in X$, *one has* $x_n \preceq u$ *for all* $n \in N$,

then f has a fixed point. Moreover, the set of fixed points of f is well ordered if and only if f has one and only one fixed point.

Proof. Since $\beta(d(x,y)) < 1$, the condition (2.10) implies that

$$\frac{1+d(x,y)}{1+\frac{1}{2}d(x,fx)} \cdot d(fx, fy) \le M(x,y) + L \cdot N(x,y). \tag{2.11}$$

On the similar lines of Theorem 2.3, we have the result.

Remark 2.2. *It is not hard to see that both functions* ψ *and* β *in all results are superfluous. But in our next result, the function* β *is not superfluous.*

Theorem 2.4. *Let* $(X,\preceq)$ *be a partially ordered set and suppose that there exists a* metric d on X such that (X,d) is a complete metric space. Let $f: X \to X$ be an increasing mapping with respect to $\preceq$ such that there exists an element $x_0 \in X$ with $x_0 \preceq fx_0$. *Suppose that*

$$d(fx,fy) \le \beta(d(x,y))M(x,y) + L \cdot N(x,y), \tag{2.12}$$

for all comparable elements $x, y \in X$, *where*

$L \ge 0$, $\beta: [0,+\infty) \to [0,1)$ with $\beta(t_n) \to 1^-$ implies $t_n \to 0$,

$$M(x,y) = \max\left\{d(x,y), \frac{d(x,fx)\cdot d(y,fy)}{1+d(fx,fy)}\right\}$$

and

$$N(x,y) = \min\{d(x,fx), d(x,fy), d(y,fx), d(y,fy)\}.$$

If

(1) f *is continuous, or*

(2) whenever $\{x_n\}$ *is a nondecreasing sequence in* X *such that* $x_n \to u \in X$, *one has* $x_n \preceq u$ *for all* $n \in N$,

then f has a fixed point. Moreover, the set of fixed points of f is well ordered if and only if f has one and only one fixed point.

The following example support our theoretical result given with Corollary 2.1.

Example 2.3. Let $X = \{0,1,2\}$ and define the partial order $\preceq$ on X by $\preceq := \{(0,0),(1,1),(2,2),(0,1)\}$. Consider the function $f: X \to X$ given as $f0 = f1 = 1$, $f3 = 0$ which is nondecreasing with respect to $\preceq$. Let $x_0 = 0$. Hence $fx_0 = f0 = 1$, so $x_0 \preceq fx_0$. Now, define the b-metric on X by $d(x,y) = (x-y)^2$ for all $x, y \in X$. Then (X,d) is a b-complete b-metric space with $s = 2$. It is easy to verify that this example satisfies all the

conditions of Corollary 2.1 for each $\beta:[0,\infty)\to[0,\frac{1}{2})$ with $t_n\to 0+$ whenever $\beta(t_n)\to\frac{1}{2}-$.

Finally, we formulate the following result (Geraghty fixed point theorem in the framework of a *b*-complete *b*-metric space):

Theorem 2.5. Let (X,d) be a b-complete b-metric space and let $s>1$. Suppose that a mapping $f:X\to X$ satisfies the condition

$$d(fx,fy)\le\beta(d(x,y))d(x,y),$$

for all $x,y\in X$, where $\beta:[0,\infty)\to[0,1)$ with $t_n\to 0+$ whenever $\beta(t_n)\to 1-$ for each sequence $t_n\in(0,\infty)$.

Question. Prove or disprove Theorem 2.5.

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УПОРЯДОЧЕННЫЕ Б МЕТРИЧЕСКИЕ ПРОСТРАНСТВА И СЖИМАЮЩИЕ ОТОБРАЖЕНИЯ ТИПА GERAGHTY

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Резюме:

В настоящей статье, благодаря новому методу, представлены новейшие результаты исследований неподвижной точки, проведенные разными авторами. Представление данных результатов подкреплены примерами.

Ключевые слова: неподвижная точка, б-метрика, сравнительный, упорядоченный, GERAGHTY-отображение, б-Коши, б-комплет.

УРЕЂЕНИ Б-МЕТРИЧКИ ПРОСТОРИ И КОНТРААКТИВНА ПРЕСЛИКАВАЊА ГЕРАГХТИЈЕВОГ ТИПА

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ОБЛАСТ: математика
ВРСТА ЧЛАНКА: оригинални научни чланак
ЈЕЗИК ЧЛАНКА: енглески

Сажетак:

Коришћењем новог приступа, у раду су представљени недавни резултате фиксне тачке, коју је установило више аутора, на много краћи и лепши начин. Наведен је и пример који то илуструје.

Кључне речи: фиксна тачка, б-метрика, упоредив, добро уређен, Герагхтијево пресликавање, б-Кошијев, б-комплет.

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EXTENSIONS OF THE BANACH CONTRACTION PRINCIPLE IN MULTIPLICATIVE METRIC SPACES

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Abstract:

In this paper, we have proven several generalizations of the Banach contraction principle for multiplicative metric spaces. We have also derived the Cantor intersection theorem in the setup of multiplicative metric spaces. Non-trivial supporting examples are also given.

Key words: Multiplicative metric, Multiplicative open ball, Multiplicative Cauchy sequence, Multiplicative contraction.

Introduction

The study of fixed points of mappings satisfying certain contractive conditions has many fruitful applications in various branches of mathematics; hence, it has extensively been investigated by many authors (Rad, et al, nd), (Radenović, et al, nd), (Mustafa, et al, 2016, pp.110-116), (Radenović, et al, 2016, pp.38-40). The Banach contraction principle has been the most versatile and effective tool in the fixed-point theory (Banach, 1922, pp.133-181). Generalization of the Banach contraction principle has been one of the most investigated branches of research. Matthews (1994, pp.183-197) introduced the concept of partial metric space as a part of the study of denotational semantics of dataflow networks, showing that the Banach contraction mapping theorem can be generalized to the partial metric context for applications in program verification. Hitzler (2001) generalized the Banach contraction principle in the context of a dislocated metric space.

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Zeyada (2005, pp.111-114) improved the work of Hitzler in a dislocated quasi metric space. Shatanawia & Nashine (2012, pp.37-43) studied the Banach contraction principle for nonlinear contraction ina partial metric space. Suzuki (2008, pp.1861-1869) characterized metric completeness by the generalized Banach contraction principle. Boyd and Wong (1969, pp.458- 464) showed that the constant used in the Banach contraction principle can be replaced by an upper semi-continuous function. Hadžić and Pap (2001) extended the contraction principle to probabilistic metric. Jainet al. (2012, pp.252-258) generalized the Banach contraction principle for cone metric spaces. There have been a number of generalizations of a metric space. Some examples of such generalizations are given above. One such generalization is a multiplicative metric space, where Özavsar and Cevikel (2012) introduced the notion of multiplicative contraction mappings and derived some fixed-point results for such mappings on a complete multiplicative metric space.

Hxiaoju, et al. (2014) established some common fixed points for weak commutative mappings on a multiplicative metric space.

In the current paper, we establish an extension of the famous Banach contraction principle in multiplicative metric spaces. The Banach theorem is extended in two ways:

1. The contraction constant depends on the multiplicative distance between the points under consideration.
2. The behavior of $d(x; Tx)$ is considered instead of the comparison of $d(Tx, Ty)$ and $d(x, y)$.

The derived results carry the fixed-point results of Dugundji and Granas (1982) in a metric space to a multiplicative metric space. Furthermore, to complete the proof of the extension of the Banach theorem, we also derived the Cantors intersection theorem in multiplicative metric spaces.

Definition 1.1. (Bashirov et al, 2008) A multiplicative metric on a nonempty set X is a mapping

$d: X \times X \to R$ satisfying the following condition:

(1) $d(x, y) \geq 1$ for all $x, y \in X$;

(2) $d(x, y) = 1$ if and only if $x = y$;

(3) $d(x, y) = d(y, x)$ for all $x, y \in X$;

(4) $d(x, z) \leq d(x, y).\ d(y, z)$ for all $x, y, z \in X$.

The pair (X,d) is called a multiplicative metric space.

Example 1.1. Let R_+^n denote the set of n-tuples of positive real numbers. And let $d^*: R_+^n \times R_+^n \to R$ be defined as

$$d^*(x,y)=\left|\frac{x_1}{y_1}\right|^* \cdot \left|\frac{x_2}{y_2}\right|^* \cdot \left|\frac{x_3}{y_3}\right|^* \cdots \left|\frac{x_n}{y_n}\right|^*$$

Where $x=(x_1, x_2, \ldots, x_n)$, $y=(y_1, y_2, \ldots, y_n) \in R_+^n$ and $|.|^* : R_+ \to R_+$ is defined as

$$|a|^* = \begin{cases} a & \text{if } a \geq 1 \\ \dfrac{1}{a} & \text{if } a < 1 \end{cases}$$

Then, clearly, $d^*(x, y)$ is a multiplicative metric (Bashirov et al, 2008).

Example 1.2. Let (X,d) be a metric space, then the mapping d_a defined on X as follows is a multiplicative metric,

$$d_a(x,y)=a^{d(x,y)} \text{ where } a>1.$$

The following definitions are given by Özavsar and Cevikel (2012).

Definition 1.2. Let (X,d) be a multiplicative metric space. If $a \in X$ and $r>1$, then a subset

$$B_r(a) = B(a;\, r) \;=\; \{x \;\in\; X \;:\; d(a;\, x) \;<\; r\}$$

of X is called a multiplicative open ball centered at a with the radius r. Analogously, one can define a multiplicative closed ball as

$$\overline{B}_r(a) = \overline{B}(a;\, r) \;=\; \{x \;\in\; X \;:\; d(a;\, x) \;\leq\; r\}$$

Definition 1.3. Let A be any subset of a multiplicative metric space (X,d). A point $x \in X$ is called a limit point of A if and only if $(A \cap B_\varepsilon(x)) - \{x\} \neq \varnothing$ for every $\varepsilon>1$.

Definition 1.4. Let (X,d) and (Y,ρ) be given multiplicative metric spaces and $a \in X$. A function $f:(X,d) \to (Y,\rho)$ is said to be multiplicative continuous at a, if for given $\varepsilon>1$, there exists a $\delta>1$ such that

$$d(x,\, a)<\delta \Rightarrow d(f(x),f(a)) \;<\; \varepsilon \text{ or equivalently } f(B(a;\delta)) \subset B(f(a);\, \varepsilon).$$

Where $B(a;\delta)$ and $B(f(a);\, \varepsilon)$

are open balls in (X,d) and (Y,ρ) respectively. The function f is said to be continuous on X if it is continuous at each point of X.

Definition 1.5. A sequence $\{x_n\}$ in a multiplicative metric space (X,d) is said to be multiplicative convergent to a point $x \in X$ if for a given $\varepsilon>1$ there exists a positive integer n_0 such that $d(x_n, x) < \varepsilon$ for all $n \geq n_0$ or equivalently, if for every multiplicative open ball $B_\varepsilon(x)$ there exists a positi-

ve integer n_0 such that $n \geq n_0 \Rightarrow x_n \in B_\varepsilon(x)$ then the sequence $\{x_n\}$ is said to bemultiplicative-convergent to a point $x \in X$ denoted by $xn \rightarrow x (n \rightarrow \infty)$.

Definition 1.6. A sequence $\{x_n\}$ in a multiplicative metric space *(X,d)* is said to be multiplicative Cauchy sequence if for every $\varepsilon > 1$ there exists a positive integer n_0 such that $d(x_n, x_m) < \varepsilon$ for all n, $m \geq n_0$.

Definition 1.7. A multiplicative metric space *(X,d)* is said to be complete if every multiplicative Cauchy sequence in *X* converges in *X* in the multiplicative sense.

Definition 1.8. Let *(X,d)* be a multiplicative metric space. A mapping $f : X \rightarrow X$ is called a multiplicative contraction if there exists a real number α where $0<\alpha<1$ such that

$$d(f(x_1), f(x_2)) \leq d(x_1, x_2)^\alpha \text{ for all } x_1, x_2 \in X.$$

Theorem 1.1. In a multiplicative metric space, every multiplicative convergent sequence is a multiplicative Cauchy sequence.

Lemma 1.1. A sequence $\{x_n\}$ in a multiplicative metric space *(X,d)* is a multiplicative Cauchy sequence if and only if $d(x_n, x_m) \rightarrow 1 \ (n, m \rightarrow \infty)$

Theorem 1.2. (*Banach Contraction Principle*): Let *(X,d)* be a multiplicative metric space and let $f: X \rightarrow X$ be a multiplicative contraction. If *(X,d)* is complete, then *f* has a unique fixed point.

Main Results

In this section, we are attempting to extend the famous Banach contraction principle into multiplicative metric spaces.

Theorem 2.1. Let *(M,d)* be a complete multiplicative metric space and let $T: M \rightarrow M$. Also assume that for each $\alpha>1$ there is a $\gamma(\alpha)>1$ such that if $d(x,Tx)<\gamma(\alpha)$ then $T(B\alpha(x)) \subset B\alpha(x)$.

If $d(T^n y, T^{n+1} y) \rightarrow 1$ for some $y \in M$, then the sequence $\{T^n y\}$ converges to a fixed point of T .

Proof. We first show that $\{T^n y\}$ is a multiplicative Cauchy sequence. Let, for the sake of brevity, define $T^n y = y_n$. Given $\alpha>1$, choose a natural number n_0 so that $d(y_n, y_{n+1}) < \gamma\sqrt{\alpha}$ for all $n \geq n_0$.

Since $d(y_n, y_{n+1}) = d(y_n, Ty_n) < \gamma\sqrt{\alpha}$ we get $T(B_{\sqrt{\alpha}}(y_n)) \subset B_{\sqrt{\alpha}}(y_n)$. This gives $y_{n+1} = Ty_n \in B_{\sqrt{\alpha}}(y_n)$ and $T^j y_n = Ty_{n+j} \in B_{\sqrt{\alpha}}(y_n)$ by induction for all $j \geq 0$. Then $d(y_k, y_j) \leq d(y_k, y_{n_0}).d(y_{n_0}, y_j) < \sqrt{\alpha}.\sqrt{\alpha} = \alpha$ for all $j,k \geq n_0$.

It means $\{y_n\} = \{T^n y\}$ is a multiplicative Cauchy sequence and, due to the completeness of *M*, converges to some point $z \in M$. Now we claim that *z=Tz*. Suppose by way of contradiction that $z \neq Tz$ then $d(z, Tz)=\beta>1$.

Choose $z_n \in B_{\sqrt[3]{\beta}}(z)$ such that $d(z_n, z_{n+1}) < \gamma\sqrt[3]{\beta}$. Then, by the hypothesis of the theorem $T(B_{\sqrt[3]{\beta}}(z_n)) \subset B_{\sqrt[3]{\beta}}(z_n)$. Therefore, $Tz \in B_{\sqrt[3]{\beta}}(z_n)$.

But since $d(Tz, z) \leq d(Tz, z_n).\ d(z_n, z) \Rightarrow d(Tz, z_n) \geq \dfrac{d(Tz, z)}{d(z_n, z)} \geq \dfrac{\beta}{\sqrt[3]{\beta}} = \beta^{\frac{2}{3}}$.

As $\beta^{\frac{2}{3}} > \sqrt{\beta}$ for β >1.

Therefore, $Tz \notin B_{\sqrt[3]{\beta}}(z_n)$ gives a contradiction. Hence, *Tz=z.* This completes the proof.

Theorem 2.2. Let *(M,d)* be a complete multiplicative metric space, and let *T: M→M* be a mapping satisfying

$$d(Tx, Ty) \leq \delta[d(x, y)]. \tag{2.1}$$

Where $\delta : [1, \infty) \to [1, \infty)$ is any non-decreasing (not necessarily continuous) mapping such that $\delta^n(t) \to 1$ for each fixed *t>1*.

Then the sequence $\{T^n x\}$ converges to a fixed point of T in M.

Proof. We claim that $\delta(t) < t$ for each *t>1*; because if $t \leq \delta(t)$ for some *t>1*, then by monotonicity $\delta(t) \leq \delta[\delta(t)]$, which by induction implies that $t \leq \delta^n(t)$ for all *n>0*, implying that $t \leq 1$, which is a contradiction. Now, by equation (2.1), we have $d(T^n x, T^{n+1} x) \leq \delta^n d(x, Tx)$. Hence $d(T^n x, T^{n+1} x) \to 1$ for each $x \in M$.

Let α be given, and $\gamma(\alpha) = \dfrac{\alpha}{\delta(\alpha)} > 1$. If $d(x, Tx) < \gamma(\alpha)$ for any $u \in B(x, \alpha)$, using multiplicative triangular inequality we have

$$d(Tu,x) \le d(Tu,Tx).d(Tx,x) \le \delta[d(u,x)].\gamma \le \delta(\alpha).\frac{\alpha}{\delta(\alpha)} = \alpha.$$

It means $Tu \in B(x,\alpha)$. The rest of the proof is followed by Theorem 2.1.

Theorem 2.3. *Let (M,d) be a complete multiplicative metric space and T: M →M be a map satisfying*

$$d(Tx,Ty) \le d(x,y)^{\delta(x,y)}. \tag{2.2}$$

Where $\delta : M \times M \to [1,\infty)$ has the property that for any closed interval *[a, b]* $\subset$ *[1, ∞),* $\sup\{\delta(x,y) \mid a \le d(x,y) \le b\} = \mu(a,b) < 1,$ here $\mu(a,b)$ denotes a maximum value of $\delta(x,y)$ for all $x,y \in [a,b]$. Then T has a unique fixed point $\upsilon \in M$ and $T^n x \to \upsilon$ for each $x \in M$.

Proof. Using condition (2.2), for any positive integer *n* and $x \in M$, we have

$$d(T^{n+1}x, T^{n+2}x) \le d(T^n x, T^{n+1}x)^{\delta(T^n x, T^{n+1}x)}$$

$$\le d(T^n x, T^{n+1}x)^{\mu(T^n x, T^{n+1}x)} < d(T^n x, T^{n+1}x)$$

That is $\{d(T^n x, T^{n+1}x)\}_n^\infty$ is a decreasing sequence and therefore converges to some $\in \geq 1$. We claim that $\in = 1$. Suppose on the contrary that $\in > 1$. Obviously, there will be some positive integer n_0 such that $d(T^n x, T^{n+1}x) \in [\varepsilon, \varepsilon+1]$ for all $n \ge n_0$. We can choose an integer $m \ge n_0$ and let $\kappa \in \mu(\varepsilon, \varepsilon+1)$, we get by inductio

$$\varepsilon \le d(T^{m+p}x, T^{m+1+p}x) \le d(T^m x, T^{m+1}x)\kappa^p \le (\varepsilon+1)\kappa^p \quad \text{for all } p \ge 0.$$

As $\kappa < 1,$ so letting $p \to \infty,$ we have $\varepsilon \le 1,$ which is a contradiction.

Now let $\alpha > 1,$ $\mu = \mu(\sqrt{\alpha}, \alpha)$ and $\gamma = \min\{\sqrt{\alpha}, \alpha^{1-\mu}\}$. Let $d(x,Tx) < \gamma$ and $z \in B(x,\alpha)$. Using multiplicative triangular inequality, we have $d(Tz,x) \le d(Tz,Tx).d(Tx,x)$. We distinguish the following two cases:

Case-1: $d(x,z) < \sqrt{\alpha}$, then

$$d(Tz,x) \le d(Tz,Tx).d(Tx,x) < d(z,x).d(Tx,x) < \sqrt{\alpha}.\sqrt{\alpha} = \alpha$$

Case-2: $\sqrt{\alpha} \le d(x,z) < \alpha,$ then

$$d(Tz,x) \le d(Tz,Tx).d(Tx,x) \le d(z,x)^{\delta(z,x)}.d(Tx,x) \le \alpha^{\mu}.\alpha^{1-\mu} = \alpha.$$

In both cases, $T(B_{\alpha}(x)) \subset B_{\alpha}(x)$. Consequently, the existence of the fixed point of T follows from Theorem 2.1.

For the uniqueness of the fixed point T, consider $Tz = z \neq w = Tw$ where $x, w \in M$. Using (2.2), we have, $d(z,w) = d(Tz,Tw) \le d(z,w)^{\delta(z,w)}$. Which for $\delta(z,w) < 1$, gives a contradiction. Hence $z = w$.

Definition 2.1. The sequence of non-empty sets $\{S_n\}$ in a multiplicative metric space M is said to be a nested sequence of sets, if

1) $S_n \supseteq S_{n+1}$, $n = 1,2,...$

2) The diameter $\delta(S_n)$ of S_n tends to 1 as $n \to \infty$.

Theorem 2.4. (Cantor's Intersection Theorem)A multiplicative metric space *(M,d)* is complete if and only if every nested sequence of closed sets has a non-empty intersection.

Proof. Suppose the multiplicative metric space M is complete and let $S_1 \supseteq S_2 \supseteq S_3 \supseteq ... \supseteq S_n \supseteq ...$ be a nested sequence of closed sets. Select a point x_n in S_n, $n = 1,2,...$ We show that $\{x_n\}$ is a Cauchy sequence. Let $\varepsilon > 1$ be given. As $\delta(S_n) \to 1$ for $n \to 1$. There will be a positive integer n_0 such that $\delta(S_n) = \sup_{a,b \in S_n} d(a,b) < \varepsilon$ for $n \ge n_0$.

Now x_m is in $S_n \supseteq S_m$ for $m \ge n$. Therefore, $x_m, x_n \in S_{n_0}$ for all $m, n > n_0$ and $d(x_m, x_n) < \varepsilon$. Hence, $\{x_n\}$ is a Cauchy sequence in M: Due to the completeness of M, $x_n \to x \in M$. Next, we are going to show that $x \in \bigcap_{n=1}^{\infty} S_n$. For any integer $n \ge n_0$, the elements $x_n, x_{n+1}, ...$ are all in S_n. As x is the limit point of the set of these points of S_n, so x is the limit point of S_n as well. Also, as S_n is closed, therefore $x \in S_n$ for $n \ge n_0$. Hence,

$x \in \bigcap_{n=1}^{\infty} S_n \neq \phi$. Conversely, suppose every nested sequence of closed sets has a non-empty intersection. We shall show that M is complete. Let $\{x_n\}$ be a Cauchy sequence in M. Then for every $\varepsilon > 1$ there will be a positive integer n_0 such that $d(x_m, x_n) < \varepsilon \ \forall\, m, n \geq n_0$.

Take $\varepsilon = 2^{\frac{1}{2}}$ and let n_1 be a positive integer such that $d(x_n, x_{n_1}) < 2^{\frac{1}{2}} \quad n_1 > n_0$.

Let $S_1 = \overline{B}(x_{n_1}, 2)$, take $\varepsilon = 2^{\frac{1}{4}}$ and let n_2 be a positive integer such that $d(x_{n_1}, x_{n_2}) < 2^{\frac{1}{4}} \quad n_2 > n_1$.

Let $S_2 = \overline{B}(x_{n_2}, 2^{\frac{1}{2}})$. Again take $\varepsilon = 2^{\frac{1}{8}}$ and let n_3 be a positive integer such that $d(x_{n_2}, x_{n_3}) < 2^{\frac{1}{8}} \quad n_3 > n_2$.

Let $S_3 = \overline{B}(x_{n_3}, 2^{\frac{1}{4}})$. Clearly S_1, S_2 and S_3 are closed and $S_1 \supseteq S_2 \supseteq S_3$. Continuing in the same way, choose $n_1 < n_2 < n_3 < \ldots < n_k < \ldots$ and closed sets $S_1 \supseteq S_2 \supseteq S_3 \supseteq \ldots \supseteq S_k \supseteq \ldots$ with $S_k = \overline{B}(x_{n_k}, 2^{\frac{1}{2^{k-1}}})$. As $\delta(S_k) \to 1$ when $k \to \infty$, therefore these sets form a nested sequence of closed sets. By our assumption $\bigcap_{k=1}^{\infty} S_k \neq \phi$. Let $x \in \bigcap_{k=1}^{\infty} S_k$, then for some

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integer k_0, $x \in S_k$ for all $k \geq k_0$. That is $d(x_{n_k}, x) < 2^{\frac{1}{2^{k-1}}}$, $k \geq k_0$. It means $x_{n_k} \to x$. But $\{x_{n_k}\}$ is a subsequence of a Cauchy sequence $\{x_n\}$, therefore, $x_n \to x \in M$. This completes the proof.

The Banach theorem can also be extended in another way, where the behavior of $d(x,Tx)$ is considered instead of comparing $d(Tx,Ty)$ and $d(x,y)$. Many of such generalizations relay on the following general principle involving minimizing sequences for suitable real valued functions:

Theorem 2.5. Let *(M,d)* be a complete multiplicative metric space and $\psi : M \to [1, \infty)$ be an arbitrary (not necessarily continuous) function. Assume that $\inf\{\psi(x).\psi(y) \mid d(x,y) \geq \beta\} = \lambda(\beta) > 1$ for all $\beta > 1$ (2.3).

Then each sequence $\{x_n\}$ in M such that $\psi(x_n) \to 1$ converges to one and the same point $z \in M$.

Proof. Let $S_n = \{x \mid \psi(x) \leq \psi(x_n)\}$. Any finite family of these nonempty sets has a nonempty intersection. We shall show that $\delta(S_n) \to 1$. As $\psi(x_n) \to 1$; so, for any given $\varepsilon > 1$, there will be a positive integer n_0 such that $\psi(x_n) < \sqrt{\lambda(\varepsilon)}$ for all $n \geq n_0$.

For any $x, y \in S_n$ with $n \geq n_0$ we have $\psi(x).\psi(y) < \lambda(\varepsilon)$. Condition (2.3) gives $d(x,y) < \varepsilon$, so $\delta(S_n) \leq \varepsilon$. But $\varepsilon > 1$ is arbitrary, so $\delta(S_n) \to 1$. Moreover, as $\delta(\overline{S}_n) = \delta(S_n) \to 1$, so, using Cantor's Intersection Theorem 2.4, we conclude that there is unique $z \in \bigcap_{n=1}^{\infty} S_n$. Since $x_n \in \overline{S}_n$ for each *n*, therefore $x_n \to z$. Now let $\{y_n\}$ be another sequence with $\psi(y_n) \to 1$, *therefore* $\psi(x_n).\psi(y_n) \to 1$, arguing as before and using relation (2.3), it follows that $d(x_n, y_n) \to 1$ and therefore $y_n \to z$.

The following theorem is an obvious consequence of the above result.

Theorem 2.6. Let *(M,d)* be a complete multiplicative metric space and $F_1 : M \to [1, \infty)$ be a continuous mapping. Assume the function $\psi(x) = d(x, F_1(x))$ satisfying condition (2.3) and $\inf_{x \in M} d(x, F_1(x)) = 1$. Then F_1 has a unique fixed point.

Proof. Notice that the Banach fixed-point theorem in a multiplicative metric space follows from theorem 2.6. If $d(F_1(x), F_1(y)) \le d(x, y)^{\alpha}$ where $\alpha \in (0, 1)$. Then condition (2.3) is valid for $\psi(x) = d(x, F_1(x))$, because

$$d(x, y)^{1-\alpha} = \frac{d(x, y)}{d(x, y)^{-\alpha}} \le \frac{d(x, y)}{d(F_1(x), F_1(y))} \le d(x, F_1(x)).d(y, F_1(y)).$$

Using $\inf_{x \in M} d(x, F_1(x)) = 1$, we get that $d(F_1^n(x), F_1^{n+1}{}_1(x)) \to 1$ for each $x \in M$. This completes the proof.

The following corollary is readily derivable from the Banach Contraction principle

Corollary 2.1. Let *(M,d)* be a complete multiplicative metric space and $B = B(x_0, r) = \{x \mid d(x, x_0) < r\}$ where $r > 1$.

Let $T : B \to M$ be a mapping such that $d(Tx, Ty) \le d(x, y)^{\lambda}$ for all $x, y \in B$ where $\lambda \in (0,1)$. If $d(Tx_0, x_0) \le r^{1-\lambda}$, then T has a unique fixed point.

Proof. Choose $\varepsilon < r$ such that $d(Tx_0, x_0) \le \varepsilon^{1-\lambda} < r^{1-\lambda}$. Next, we show that *T* maps the closed ball $C = \{x \mid d(x, x_0) \le \varepsilon\}$ into itself. If $x \in C$, then using the contractive condition of *T* and multiplicative triangular inequality we have $d(Tx, x_0) \le d(Tx, Tx_0).d(Tx_0, x_0) \le d(x, x_0)^{\lambda}.\varepsilon^{1-\lambda} \le \varepsilon^{\lambda}.\varepsilon^{1-\lambda} = \varepsilon$. As *C* is closed, so the Banach Contraction Principle completes the proof.

We conclude with the following example which supports Theorem 2.3.

Example 2.1. Let $M = [0.01, 1]$. Consider the multiplicative metric $d : M \times M \to [1, \infty)$ defined by $d(x, y) = e^{|\frac{1}{x} - \frac{1}{y}|}$. Then *(M,d)* is a complete multiplicative metric space. The mapping $T : M \to M$ defined by $T(x) = \frac{3}{5 + x}$, satisfies the following multiplicative contractive condition $d(Tx, Ty) \le d(x, y)^{\delta(x,y)}$, where $\delta : M \times M \to [0, \infty)$ defined $\delta(x, y) = \frac{x.y}{2}$, has the property that for any closed interval

$$[a, b] \subset [1, \infty), \sup\{\delta(x, y) \mid a \le d(x, y) \le b\} = \mu(a, b) < 1.$$

Obviously, T has a unique fixed point $0.5413812651 \in M$.

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РАСШИРЕНИЕ БАНАХОВЫХ ПРИНЦИПОВ СЖАТИЯ В МУЛЬТИПЛИКАТИВНОМ МЕТРИЧЕСКОМ ПРОСТРАНСТВЕ

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Резюме:

В данной статье мы доказали несколько обобщений Банаховых принципов сжатия в мультипликативном метрическом пространстве. Мы также развили применяемуюКанторовутеорему подмножеств при образовании мультипликативных метрических пространств,подтвердив ее нетривиальными примерами.

Ключевые слова: мультипликативная метрика, мультипликативный открытый шар, последовательность Коши, мультипликативное сжатие.

ПРОШИРИВАЊЕ БАНАХОВОГ ПРИНЦИПА КОНТРАКЦИЈЕ НА МУЛТИПЛИКАТИВНЕ МЕТРИЧКЕ ПРОСТОРЕ

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Сажетак:

У овом раду је доказано неколико генерализација Банаховог принципа контракције за мултипликативне метричке просторе. Такође, развијена је Канторова теорема интерсекције при

образовању мултипликативних метричких простора, подржана нетривијалним примерима.

Кључне речи: мултипликативна метрика, мултипликативна отворена кугла, мултипликативни Кошијев низ, мултипликативна контракција.

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KINETICS OF THE NON-ISOTHERMAL DESORPTION OF ETHANOL ABSORBED ONTO CMS-3A

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Abstract:

The kinetics of the desorption of ethanol previously absorbed onto carbon molecular sieves (CMS-3A) was studied using the non-isothermal thermogravimetric technique. The dependence of activation energy ($E_{a,\alpha}$) for a particular degree of desorption (α) was established. It was confirmed that the non-isothermal desorption of ethanol was a kinetically complex process. A novel mathematical model for the kinetics of non-isothermal desorption for the absorbed ethanol is established. This model is based on the proposed dependence of the specific desorption rate on time/temperature. The correlation dependences of the model parameters β and η on heating rates were established. A general kinetic equation for the non-isothermal desorption of ethanol was developed. It was found that the specific desorption rate at every single heating rate increases, whereas E_a, decreases during the desorption process.

Key words: dependant, absorbers, molecular sieves, analytical models, model, zeolites, CMS-3A, kinetics, ethanol, desorption.

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Introduction

Bioethanol nowadays presents a main alternative source for the economic production of novel fuels and ethanol (Kosaric, et al, 2001). Ethanol is produced by fermentation of sugars obtained by hydrolyses of biomass. Three sources of biomass are commonly used: sugar, corn and lignocellulose materials. The most promising source is the lignocellulose biomass because it can use agricultural and forest residues and prevent the heated fuel-versus-food debate (Hashi, et al, 2010, pp.4628-4637). The only barrier for a broad application of production of ethanol is a high production cost (Kaminski, et al, 2008, pp.95-102).

Produced bioethanol contains a certain amount of water. The distillation process used for bioethanol separation and purification requires a large amount of energy which is approximately equal to 50% of the combustion energy of produced bioethanol (Fujita, et al, 2011, pp.869-879). Selective ethanol adsorption on a hydrophobic material of the zeolite type is a way to reduce the energy consumption of this process, presently the most promising procedure for an energetically rational bioethanol production (Adnadjevic, Jovanovic, 2012, pp.761-768). The introduction of this new separation process for bioethanol production requires solving a novel problem of cheep and effective selective procedure of adsorbed ethanol desorption onto a zeolite type adsorbent. The key role in this solution is in the kinetics of ethanol desorption from the zeolite adsorbent. It was shown that the most effective adsorbents are carbon molecular sieves such as CMS - 3A. Knowing the kinetics of ethanol desorption can contribute to better and more economical production of bioethanol. Unfortunately, to the best of our knowledge, the literature data is sparse with data concerning this topic.

Fujita and co-workers investigated the kinetics of desorption of ethanol and water from various types of commercial zeolite (MSC-3A, 4A, -5A, -6A, -7A, HiSiV3000, ZSM-5 (Si02/Al03 =30), hydrophilic 5A) in the gaseous phase and evaluated the effectiveness of the proposed process (Fujita, et al, 2011, pp.869-879). The desorption of 1-buthanol from water solution adsorbed onto ZSM-5 with a high Si/Al ratio was discussed in the work of Saravanan et al. (Saravanan, et al, 2010, pp.68-69). Oudshoorn et al. investigated the desorption rate of 1- buthanol from zeolite CVB28014, CVB901 (Oudshoorn, et al, 2012, pp.167-172).

Keeping that in mind, this work thoroughly investigates the kinetics of the non-isothermal desoprption of ethanol adsorbed onto carbon molecular

sieves (CMS-3A). Therefore, a kinetic model, kinetic complexity and the values of the kinetics parameters were determined and discussed.

Materials and Methods

Materials

The following materials were used: a carbon molecular sieve type 3A (CMS-3A), produced by Takeda Chem. Ind., Japan; ethanol 99.8 vol. % of p.a. purity purchased from Hemos, Belgrade, Serbia, and bidistilled water obtained from Hemofarm, Serbia. Before use, the CMS-3A was thermally activated at a temperature of 393 K for 2 hours, cooled and kept in a dessicator until use.

Characterization

The texture properties of the activated sample used were determined by N2 (77 K) adsorption using a Micrometrics ASAP 2010 volumetric adsorption apparatus. The BET surface area was measured from the adsorption isotherms by applying the Brunauer-Emmett-Teller equation to calculate the micropore volume (V_{mp}). The total volume (V_t) was obtained at a relative pressure of 0.99. The pore size distribution (PSD) was obtained by the Horvath-Kawazoe analysis.

Sample preparation

Ethanol was absorbed onto the CMS-3A as follows. One gram of thermally activated CMS-3A was added to 50 mL of ethanol. Ethanol adsorption was undertaken for 24 hours. The ethanol adsorbed-CMS (CMS-ethanol) sample was separated from the ethanol excess by decantation. The sample was kept in the exicator to prevent ethanol desorption.

Thermogravimetric measurements

The non-isothermal thermogravimetric curves were recorded using a TA Instruments SDT simultaneous TGA-DSC thermal analyzer, model 2960. These experiments were performed with the CMS-ethanol absorbed

samples weighing 20 ± 5 mg. The samples were placed in the platinum pans under (99.9995 vol. %) nitrogen flowing at a rate of 20 mL min^{-1}. Four different heating rates (v_h = 5, 10, 15 and 20 K min^{-1}) were used in this study. All experiments in this work were conducted in the temperature range from ambient temperature up to 400 K. For isothermal methods, it is necessary that the process of desorption is performed at a lower temperature range from ambient to 500K. The original mass loss versus temperature (TG) curves obtained at a constant heating rate were transformed into the degree of desorption (α) versus temperature curves by means of the following equation:

$$\alpha = \frac{m_0 - m}{m_0 - m_f} \tag{1}$$

where m_0, m and m_f refer to the initial, actual and final mass of the sample.

Kissinger–Akahira–Sunose (KAS) method

The Kissinger-Akahira-Sunose method (Akahira, Sunose, 1971, pp.22-31) is the isoconversional integral method which uses Coats-Redfern approximation (Coats, Redfern, 1964, pp.1273-1278) of the temperature integral that leads to the equation:

$$\ln\left(\frac{v_h}{T^2}\right) = \ln\left(\frac{AR}{E_a g(\alpha)}\right) - \frac{E_a}{RT} \tag{2}$$

where $g(\alpha)$ is the integral form of the selected kinetic model. For α =const., the plot of $\ln(v_h / T^2) vs. T^{-1}$ should be a straight line the slope of which can be used to evaluate the apparent activation energy.

Kinetic model

Desorption kinetics model

The ethanol desorption process is affected by many parameters such as temperature, time, pressure, ethanol concentration, pH of the solution, as well as the structural characteristics of carbon molecular sieves. The mathematical models of desorption presented bellow are based on the following assumptions listed below: (a) The desorption process is a kinetically complex process; (b) Leaving the molecules of a certain part of

the absorbed phase (desorption) leads to structural changes in the absorbed phase and its nearby surroundings (structural rearrangement); (c) The desorption rate is significantly higher than the structural rearrangement rate; (d) As a consequence of the above, the specific desorption rate (k) is a function of both time (t) and temperature (T), which can be described by the equation:

$$k = \frac{\beta}{\eta}\left(\frac{t}{\eta}\right)^{\beta-1} \tag{3}$$

i.e

$$k = \frac{\beta}{\eta}\left(\frac{T-T_0}{v_h\eta}\right)^{\beta-1} \tag{4}$$

where β and η are the Weibull's parameters, To is the initial temperature and vh is the heating rate; (e) the rate of desorption (dN/dt) is proportional to the amount of the remaining molecules in the adsorbed phase. In this case, the desorption rate is given as:

$$\frac{dN}{dT} = \frac{k}{v_h}\left(N_0 - N\right) \tag{5}$$

where N_0 is the amount of the adsorbed molecules in the beginning of the desorption process, and N is the amount of the desorbed molecules at T. Introducing Eq (4) into Eq (5) yields:

$$\frac{dN}{dT} = \frac{\beta}{v_h\eta}\left(\frac{T-T_0}{v_h\eta}\right)^{\beta-1}\left(N_0 - N\right) \tag{6}$$

The separation of the variables in equation (3) leads to:

$$\int_0^N \frac{dN}{\left(N_0 - N\right)} = \int_0^T \frac{\beta}{v_h\eta}\left(\frac{T-T_0}{v_h\eta}\right)^{\beta-1} dT \tag{7}$$

The integration of equation (7) should be done in the limits of N from 0 to N and of T from To to T, to yield:

$$\ln\left(\frac{N_0 - N}{N_0}\right) = \left(\frac{T-T_0}{v_h\eta}\right)^{\beta} \tag{8}$$

The results is:

$$\frac{N_0 - N}{N_0} = \exp\left[-\left(\frac{T - T_0}{v_h \eta}\right)\right]^{\beta} \tag{9}$$

Since: $\alpha = N / N_0$, equation (9) is transformed into the form:

$$\alpha = 1 - \exp\left[-\left(\frac{T - T_0}{v_h \eta}\right)\right]^{\beta} \tag{10}$$

Results and discussion

Figure 1 shows the thermogravimetric curves for the desorption of ethanol from CMS at various heating rates.

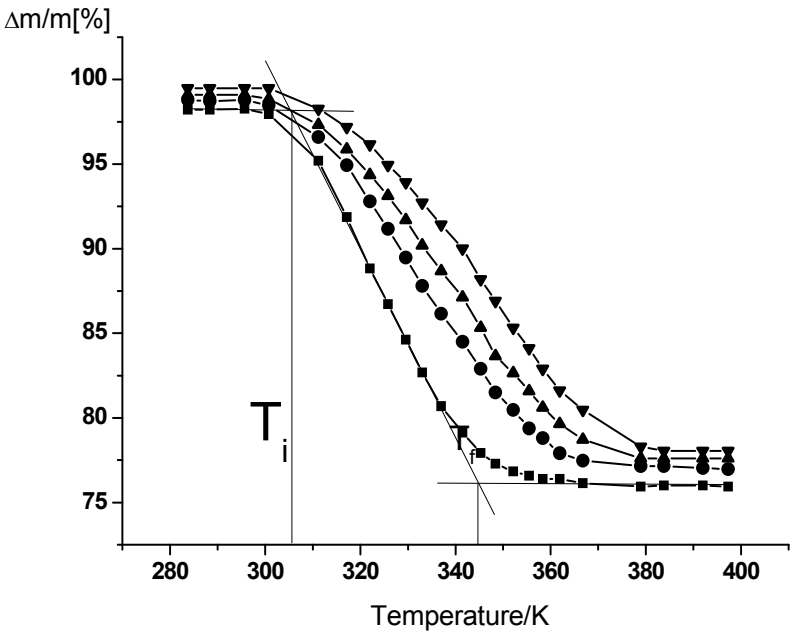

Figure 1 – The TG curves for the desorption of ethanol from CMS at various heating rates: 5Kmin^{-1}, ●- 10Kmin^{-1} ▲- 15Kmin^{-1} ▼- 20Kmin^{-1}

Рис. 1 – TG кривая десорбции этанола с CMS при разных скоростях нагревания: 5 K мин-1, ●- 10 K мин-1 ▲- 15 K мин-1 ▼- 20 K мин-1

Слика 1 – TG крива десорпције етанола са CMS на различитим брзинама загревања: 5Kmin^{-1}, ●- 10Kmin^{-1} ▲- 15Kmin^{-1} ▼- 20Kmin^{-1}

As it can be seen from Figure 1, the TG curves for the desorption of ethanol at all investigated heating rates are of a complex sigmoid shape. As it is obvious from the TG curves, both the initial temperature (T_i) and the final temperature (T_f), the reaction interval ($\Delta T = T_f - T_i$) and the degree of asymmetry of the curves change with the change in the heating rates. Table 1 summarizes the effects of heating rates on the values of T_i, T_f ΔT and the residual ($\Delta m / m$).

Table 1 – Data for the heating rates, initial temperatures, final temperatures, reaction intervals and percentage of residual masses for Fig.1
Таблица 1 – Значения температуры в начале десорбции, при завершении десорбции, температурного интервала и остаток массы в процентах
Табела 1 – Вредности температуре почетка десорпције, температуре завршетка десорпције, температурског интервала и процентни остатак масе

v_h [K/min]	T_i [K]	T_f [K]	ΔT [K]	$\Delta m / m$ [%]
5	305.63	344.59	38.96	76.04
10	308.09	358.63	50.54	76.97
15	310.54	366.65	56.11	77.72
20	312.29	373.73	61.44	78.02

As it is obvious from the results presented in Table 1, the increase of the heating rate leads to the increase in the values of T_i, T_f and ΔT, where the residual insignificantly varies within the experimental error. In order to preliminary determine the kinetic model of ethanol desorption, the shape of the dependence $d\alpha / dt$ on α is analyzed. (Khawam, Flangan, 2005, pp.10073-10080). The dependence of $d\alpha / dt$ on α is presented in Figure 2.

The dependence of $d\alpha / dt$ on α shows a broad asymmetric peak with a clear maximum - $\alpha_{\max}$. With the increase of the heating rate, the value of $\alpha_{\max}$ increases almost linearly. Since the dependence of $d\alpha / dt$ on α has a complex shape, the dependence of $E_{a,\alpha}$ on α is determined by applying the KAS method. The dependence of $E_{a,\alpha}$ on α is shown in Figure 3.

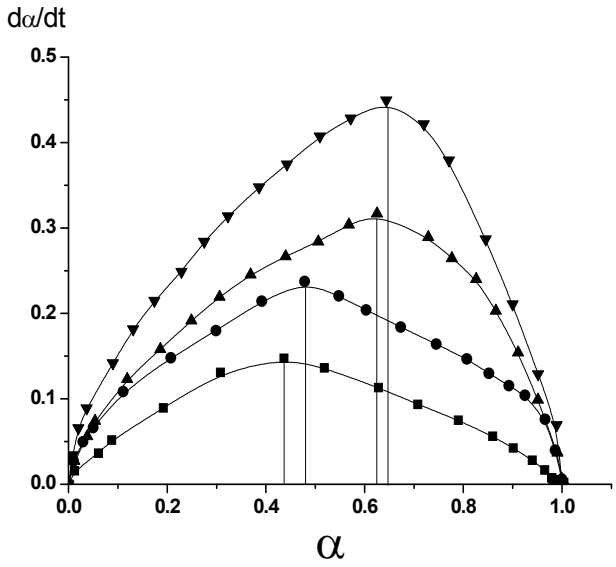

Figure 2 – The dependence of $d\alpha / dt$ on α at various heating rates:
■- 5 K min^{-1},●- 10 K min^{-1}▲- 15 K min^{-1}▼- 20 K min^{-1}
Рис. 2 – зависимость $d\alpha / dt$ при разных скоростях нагревания:
■- 5 K мин-1,●- 10 K мин-1▲- 15 K мин-1▼- 20 K мин-1
Слика 2 – зависност $d\alpha / dt$ на различитим брзинама загревања:
■- 5 K min^{-1},●- 10 K min^{-1}▲- 15 K min^{-1}▼- 20 K min^{-1}

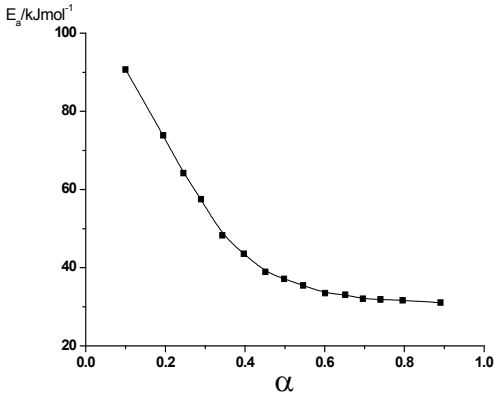

Figure 3 – The dependence of $E_{a,\alpha}$ on α

Рис. 3 – Зависимость $E_{a,\alpha}$ от α

Слика 3 – зависност $E_{a,\alpha}$ od α

The values of $E_{a,\alpha}$ decrease with the increase in the values of α. The analysis of the shape of the dependence of $E_{a,\alpha}$ on α clearly reveals two characteristic shapes of changes in $E_{a,\alpha}$ with the increasing α. In the range of $0 \leq \alpha \leq 0.25$, $E_{a,\alpha}$ decreases almost linearly with increasing the α values from ~100 kJ mol^{-1} to ~60 kJ mol^{-1}. In contrast to this, when $\alpha \geq 0.25$, the increase of α leads to concave decrease in the value $E_{a,\alpha}$ from ~60 kJ mol^{-1} to ~20 kJ mol^{-1}. A complex shape of the dependence of $E_{a,\alpha}$ on α, in accordance with Vyazovkin's criteria (Vyazovkin, Linert, 1995, pp.109-118), indicates that the process of desorption of the ethanol from the CMS is a kinetics complex process which takes place through numerous elementary stages. In regard to that, the ability of a mathematical description of the kinetics of ethanol desorption with equation (10) was evaluated. Figure 4 presents the dependence of $\ln\left[-\ln\left(1-\alpha\right)\right]$ on $\ln\left[\frac{T-T_0}{v_h}\right]$ at different heating rates.

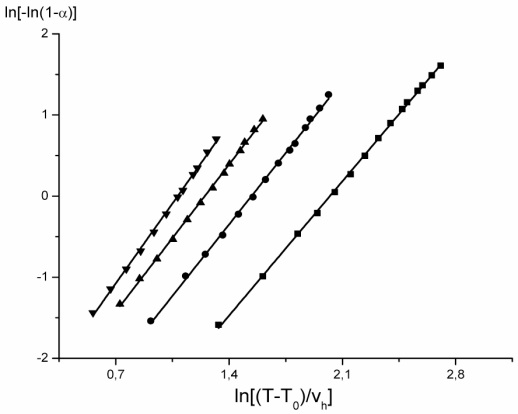

Figure 4 – Dependence of $\ln\left[-\ln\left(1-\alpha\right)\right]$ on $\ln\left[\frac{T-T_0}{v_h}\right]$ at different heating rates:
■- 5 K min-1, ●- 10 K min-1▲- 15 K min-1▼- 20 K min-1

Рис. 4 – Зависимость $\ln\left[-\ln\left(1-\alpha\right)\right]$ от $\ln\left[\frac{T-T_0}{v_h}\right]$ при разных скоростях нагревания:
■- 5 K мин-1, ●- 10 K мин-1▲- 15 K мин-1▼- 20 K мин-1

Слика 4 – Зависност $\ln\left[-\ln\left(1-\alpha\right)\right]$ од $\ln\left[\frac{T-T_0}{v_h}\right]$ на различитим брзинама загревања:
■- 5 K min-1, ●- 10 K min-1▲- 15 K min-1▼- 20 K min-1

Table 2 – Values of the Weibull's parameters at different heating rates
Таблица 2 – Значения параметров Вейбулла при разных скоростях нагревания
Табела 2 – Вредности Вејбулових параметара на различитим брзинама загревања

v_h [K/min]	β	η[min]
5	2.35	7.57
10	2.47	4.69
15	2.63	3.47
20	2.82	2.95

Obviously, the dependencies of $\ln\left[-\ln\left(1-\alpha\right)\right]$ on $\ln\left[\frac{T-T_0}{v_h}\right]$ for all of the investigated heating rates are linear. The values of the parameters β and η were calculated based on the slopes and intercepts the dependencies of $\ln\left[-\ln\left(1-\alpha\right)\right]$ on $\ln\left[\frac{T-T_0}{v_h}\right]$. The effect of heating rates on the Weibull's parameters β and η is shown in Table 2.

As it can be seen from the results presented in Table 3, the increase in the heating rates leads to the increase in the values of the parameter β while the values of the parameter η decrease. The found changes in the values of the parameters β and η can be mathematically described by the expressions:

$$\beta\left(v_h\right)=\exp\left(0.827+0.05v_h+0.0003v_h^2\right) \tag{11}$$

$$\eta\left(v_h\right)=\exp\left(2.658-0.143v_h+0.003v_h^2\right) \tag{12}$$

The mathematical expressions (11) and (12) enable to derive an equation which can successfully describe the kinetics of the investigated process as a function of temperature and heating rates:

$$\frac{d\alpha}{dT}=\frac{\beta\left(v_h\right)}{v_h\eta\left(v_h\right)}\left[\frac{\left(T-T_0\right)}{v_h\eta\left(v_h\right)}\right]^{\beta\left(v_h-1\right)}\exp\left[-\left(\frac{T-T_0}{v_h\eta\left(v_h\right)}\right)^{\beta\left(v_h\right)}\right] \tag{13}$$

Based on the knowledge on the values of the parameters β and η by using Eq (4), it is possible to calculate the values of a specific desorption rate for different temperatures at different heating rates. Figure 5 pre-

sents the dependence of the specific desorption rate with temperatures for different heating rates.

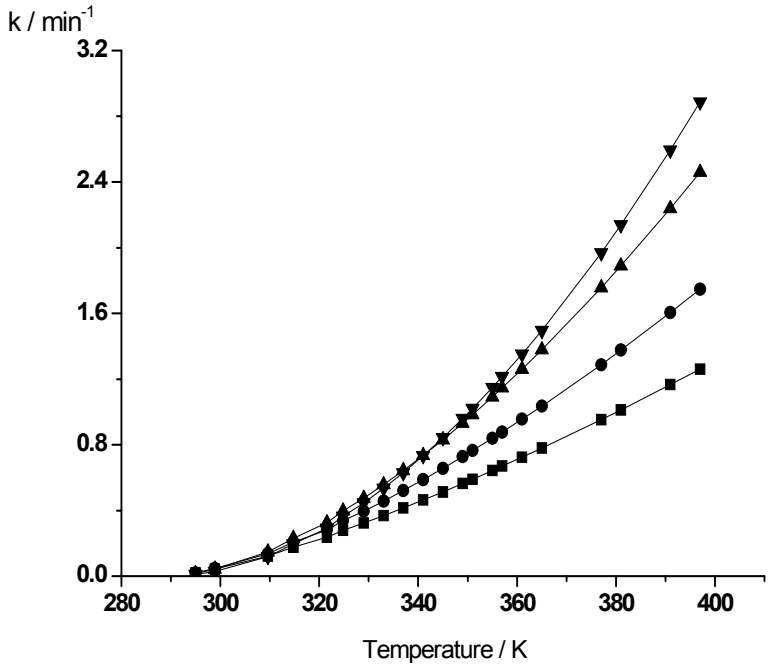

Figure 5 – Dependence of k on temperature at different heating rates:
■- 5 K min^{-1}, ●- 10 K min^{-1} ▲- 15 K min^{-1} ▼- 20 K min^{-1}
Рис. 5 – Зависимость k от температуры при различных скоростях нагревания
■- 5 K мин$^{-1}$, ●- 10 K мин$^{-1}$ ▲- 15 K мин$^{-1}$ ▼- 20 K мин$^{-1}$
Слика 5 – Зависност k од температуре на различитим брзинама загревања
■- 5 K min^{-1}, ●- 10 K min^{-1} ▲- 15 K min^{-1} ▼- 20 K min^{-1}

The increase in temperature leads to the increase in the values of the specific desorption rate at all of the investigated heating rates. Also, the increase in the heating rates at all investigated temperature values leads to the increase in the values of the specific desorption rate. The established dependencies of k on T allow applying the Arrhenius equation to calculate the values of activation energies at different temperatures for different heating rates. The dependence of E_a on temperature at the investigated heating rates is presented in Figure 6.

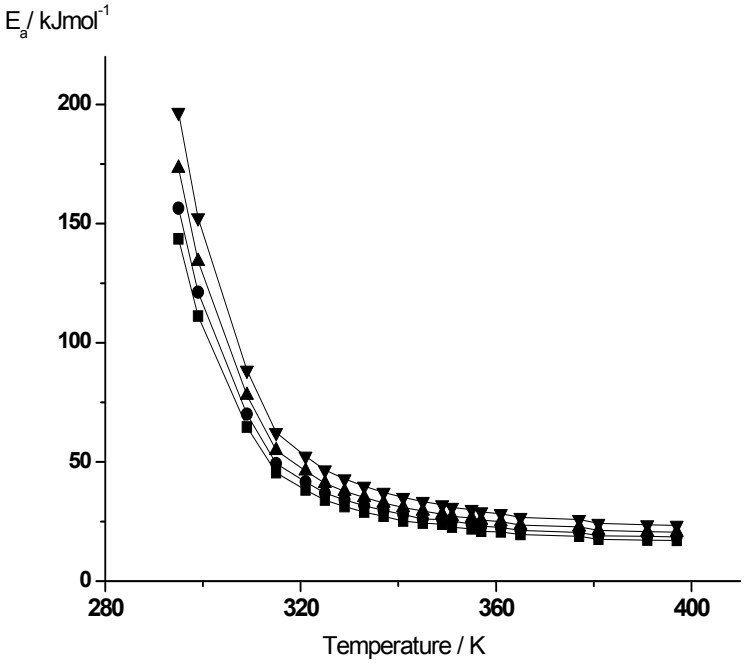

Figure 6 – The dependence of E_a on temperature at different heating rates:
■- 5 K min^{-1}, ●- 10 Kmin^{-1}▲- 15 K min^{-1}▼- 20 K min^{-1}

Рис. 6 – Зависимость E_a от температуры при различных скоростях нагревания
■- 5 K мин$^{-1}$, ●- 10 K мин$^{-1}$▲- 15 K мин$^{-1}$▼- 20 K мин$^{-1}$

Слика 6 – Зависност E_a од температуре на различитим брзинама загревања:
■- 5 K min^{-1}, ●- 10 Kmin^{-1}▲- 15 K min^{-1}▼- 20 K min^{-1}

The E_a value decreases with the increasing temperature at all of the investigated heating rates. The two characteristic shapes of changes of $E_{a,T}$ with increasing T are obvious. In the range of 290 ≤ T ≤ 315 K, the dependence $E_{a,T}$ on T almost linearly decreases with increasing temperature, whereas at temperatures 315 ≤ T ≤ 400 K, the value of E_a decreases concavely with increasing temperature. At a particular value of temperature, the value of E_a increases with the increase in the heating rate. Based on the dependence of E_a on temperature at a particular heating rate, it is

possible to get the dependence of $E_{a,\alpha}$ on α for that heating rate. Figure 7 presents the dependence of $E_{a,\alpha}$ on α for different heating rates.

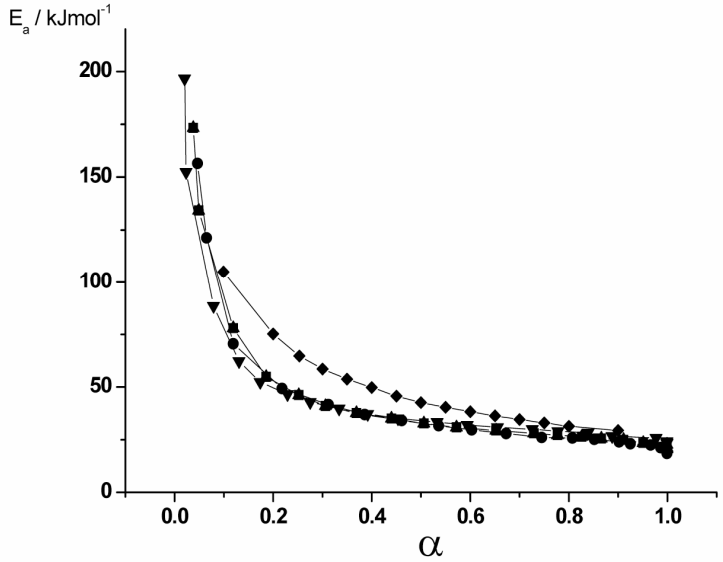

Figure 7 – Dependence of $E_{a,\alpha}$ on α for different heating rates

Рис. 7 – Зависимость E_a от α при различных скоростях нагревания

Слика 7 – Зависност $E_{a,\alpha}$ од α на различитим брзинама загревања

The curves of the dependence of $E_{a,\alpha}$ on α at all investigated heating rates are of similar shapes. The curves of the dependence of $E_{a,\alpha}$ on α show two different shapes of changes of the dependence of $E_{a,\alpha}$ on α. The two characteristic shapes of changes of $E_{a,\alpha}$ with increasing α are obvious. For the range of values $0 \leq \alpha \leq 0.2$, the dependence $E_{a,\alpha}$ on α linearly decreases with increasing α. For the values of $\alpha > 0.2$, the values of $E_{a,\alpha}$ decrease concavely with increasing $E_{a,\alpha}$.The comparison of the shapes of the dependences of E_a on α at different heating rates with the dependence of $E_{a,\alpha}$ on α obtained by the isoconversion method (Fig 3) clearly shows their mutual similarity, especially at extremely low and high degrees of desorption. The found similarity confirms physical reality of the previously suggested model for the non-isothermal desorption based on the assumption about the changes in the values of the specific rate of

desorption with temperature. Since with the increasing temperature the specific rate of desorption increases more rapidly than the rate of internal rearrangement of ethanol's molecules in the absorbed phase, the activation energy decreases, the kinetics complexity changes and the specific rate of desorption increases.

Conclusion

The non-isothermal desorption of ethanol absorbed onto CMS-3A is a kinetically complex process. Kinetic's complexity of the desorption of ethanol is a consequence of the changes in the specific rate of desorption and activation energy with temperature. The conversion kinetics curves of the non-isothermal desorption of ethanol, at all heating rates, can be entirely mathematically described by the suggested model. The correlation dependences of the parameters of the kinetics model on heating rates are established. A general kinetics equation of the non-isothermal desorption of ethanol is developed. It was found that the value of the specific desorption rate of ethanol, at every single heating rate, increases with the increase in temperature, whereas the activation energy decreases. The functional dependences of activation energy on time for each heating rate were determined. The results obtained by this work can be used to enhance the knowledge of the desorption kinetics of ethanol, wich is a key factor for its more economical production.

Symbols

E_a [kJ mol^{-1}]	activation energy
$E_{a,\alpha}$ [kJ mol^{-1}]	activation energy at α
$E_{a,T}$ [kJ mol^{-1}]	activation energy at T
V_{mp} Vmp [cm^{3}g^{-1}]	micropore volume
V_t [cm^{3}g^{-1}]	total volume
d [nm]	average pore size
m_0 [g]	the initial mass of the sample
m [g]	actual mass of the sample
m_f [g]	final mass of the sample
$\Delta m / m$ [%]	percentage of residual mass
$g(\alpha)$	integral form of the selected kinetic mode

T [K]	temperature
T^{-1} [K^{-1}]	inverse temperature
T_i [K]	initial temperature at TG
T_f [K]	final temperature at TG
ΔT [K]	reaction interval
R [J mol^{-1}K^{-1}]	universal gas constant (8.314)
k [min^{-1}]	specific desorption rate
t [min]	time
T_0 [K]	initial temperature
dN / dt	rate of desorption
N_0	amount of the adsorbed molecules in the beginning of the desorption process
N	amount of the desorbed molecules at temperature
v_h [K min^{-1}]	heating rate

Greek symbols

α α [-]	degree of desorption
α_{max} [-]	maximum degree of desorption
β [-]	Weibull's parameter
η [min]	Weibull's parameter

Abbreviations

CMS-3A	Carbon molecular sieves type 3A
CMS-ethanol	Ethanol adsorbed carbon molecular sieves
PSD	Pore size distribution
TG	Thermogravimetric curve
KAS method	Kissinger-Akahira-Sunose method
MSC-3A	Molecular Sieving Carbon type 3A
MSC-4A	Molecular Sieving Carbon type 4A
MSC -5A	Molecular Sieving Carbon type 5A
MSC -6A	Molecular Sieving Carbon type 6A
MSC -7A	Molecular Sieving Carbon type 7A
HiSiV3000	Silicalite zeolite
ZSM-5	Zeolite Socony Mobil–5
CVB28014	Zeolite ammonium ZSM-5
CVB901	Zeolite H-SDUSY

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НЕИЗОТЕРМИЧЕСКАЯ КИНЕТИКА ДЕСОРБЦИИ ЭТАНОЛА, АБСОРБИРОВАННОГО НА УГЛЕРОДНОМ МОЛЕКУЛЯРНОМ СИТЕ CMS-3A

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ЯЗЫК СТАТЬИ: английский

Резюме:

В данной статье описаны проведенные исследования по кинетике десорбции эталона, абсорбированного на углеродном молекулярном сите CMS-3A. Главным источником биоэтанола являются: сахар, кукуруза и лигноцеллюлозные материалы. Выработанный биоэтанол содержит определенное количество воды. Для его очистки используются различные сепарационные методы, которые в настоящий момент еще недостаточно испытаны. Главная проблема очистки биоэтанола заключается в высокой стоимости процедуры и больших затратах энергии – на 50% превышающих производимую биоэтанолом энергию. Селективная адсорбция этанола на цеолите значительно снижает затраты энергии при производстве, но, к сожалению, данный метод требует много времени. В целях улучшения кинетики десорбции могут применятся различные технологии, однако они на сегодняшний день недостаточно испытаны. Одним из самых практичных и наиболее экономичных методов очистки биоэтанола является десорбция этанола на углеродном молекулярном сите, при этом вода остается на поверхности углеродного молекулярного сита. С учетом того, что данный метод недостаточно испытан, необходимо полагаться на знания о кинетике десорбции этанола на цеолитах. Хотя на сегодняшний день опубликовано малое количество научных работ, посвященных исследованиям кинетики десорбции этанола на цеолитах. В данной работе применена неизотермическая термогравиметрическая техника. В ходе исследования была утверждена полная зависимость энергии активации от степени десорбции, а также установлена модель процесса десорбции. Данная модель основана на полной зависимости скорости десорбции от времени и температуры. Благодаря применению данной модели можно повлиять на скорость процесса десорбции и энергию активации с температурой. Математическая модель, описанная в данной работе основана на полной зависимости скорости процесса десорбции и энергии активации от

температуры. Данная модель также отражает последовательность этапов процесса десорбции. Настоящая модель кинетики процесса десорбции этанола может значительно улучшить технологию производства биоэтанола и уменьшить производственные затраты.

Ключевые слова: зависимость, абсорбенты, молекулярные сита, аналитические модели, модели, цеолиты, CMS-3A, кинетика, этанол, десорбция.

НЕИЗОТЕРМНА КИНЕТИКА ДЕСОРПЦИЈЕ ЕТАНОЛА АДСОРБОВАНОГ НА УГЉЕНИЧНОМ МОЛЕКУЛСКОМ СИТУ CMS-3A

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ЈЕЗИК ЧЛАНКА: енглески

Сажетак:

У овом раду проучавана је кинетика десорпције етанола претходно адсорбованог на угљеничном молекулском ситу CMS-3A. Главни извори биоетанола су ферментабилни шећери, кукуруз и лигноцелулозни отпадни материјал. Произведени биоетанол садржи одређену количину воде, а да би се пречистио користе се разне сепарационе методе које још нису довољно испитане. Главни проблем при пречишћавању биоетанола је висока цена, као и знатан утрошак енергије који представља више од 50% енергије коју биоетанол производи. Селективна адсорпција етанола са зеолита знатно смањује утрошак енергије при производњи. Нажалост, ова метода је веома спора. Ради побољшања кинетике десорпције користе се различите технике, које нису довољно испитане. Једну од практичнијих и јефтинијих метода која се користи при пречишћавању биоетанола представља десорпција етанола са угљеничног молекулског сита, при чему вода остаје задржана на угљеничном молекулском ситу. Међутим, ова метода није довољно испитана, а ради побољшања производње (брзине производње) потребно је познавати кинетику десорпције етанола са зеолита. Мало је научних радова и литературе који проучавају кинетику десорпције (брзину десорпције) етанола са зеолита За одређивање кинетике десорпције у овом раду је коришћена неизотермна термогравиметријска техника.

Установљена је комплексна зависност енергије активације од степена десорпције, као и математички модел по којем се десорпција одиграва. Овај модел заснован је на комплексној зависности брзине десорпције од времена и температуре. Због комплексности модела долази до промене брзине десорпције и енергије активације са температуром. Математички модел установљен у овом раду заснива се на комплексној зависности брзине десорпције и енергије активације од температуре и показује на који начин се десорпција одиграва у неколико ступњева. Познавање кинетике процеса десорпције етанола може допринети бољој и економичнијој производњи биоетанола.

Кључне речи: зависност, апсорбенти, молекулска сита, аналитички модели, модели, зеолити, CMS-3A, кинетика, етанол, десорпција.

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STRUCTURE AND PROPERTIES OF Ni22Cr10Al1Y COATINGS DEPOSITED BY THE VACUUM PLASMA SPRAY PROCESS

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Summary:

In this study, the aim was to deposit layers of the Ni22Cr10Al1Y coating using the vacuum plasma spray process to protect gas turbine engine components from oxidation and high-temperature corrosion. The coating can significantly affect the properties of the substrate because it forms a composite together with the substrate. The type of the coating deposition process and coating heat treatment, together with the substrate, significantly affect its resistance to high temperature creep. Ni22Cr10Al1Y powder was deposited with a vacuum plasma spray system of the Plasma Technik - AG company using the control panel A-2000 and the plasma gun F4. The coating deposited on the substrate of INCONEL X-750 alloy was thermally treated at 1100°C for 2 hours in a protective atmosphere of argon. The particle morphology was tested by scanning electron microscopy.The microhardness of layers was tested by the $HV_{0.3}$ method and the bond strength was tensile tested, in accordance with the standard Pratt & Whitney. The microstructure of the deposited coating layers was examined under a light microscope. Coating etching was done by mixing 2.5ml of nitric acid HNO_3 with 7.5ml of hydrofluoric acid HF. The microstructure of the etched coating before and after heat treatment, as well as the thickness of the diffusion zone, were analysed under a light microscope, based on which the coating quality was later assessed.

Keywords: v*acuum, substrates, structural properties, plasmas, layers, coatings.*

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Introduction

The components of hot sections, such as gas turbine blades, have to withstand various stresses and severe environmental conditions at the operating temperatures of 900°C to 1000°C. The structures of alloys for producing hot sections are developed with optimum mechanical properties and MCrAlY coatings to provide the resistance of hot sections to high-temperature oxidation and hot corrosion (Mrdak, 2016, pp.1-25). In recent years, MCrAlY alloys have been widely used while vacuum plasma spraying (VPS) is the leading process used for depositing coatings on hot sections such as blades which are exposed to aggressive gases at high temperatures. MCrAlY coatings have been extensively studied in recent years; they have shown good properties and adequate oxidation resistance to hot corrosion (Wang, et al, 2002, p.70), (Mrdak, et al, 2015, pp.337-343). There are two basic systems of coatings used on gas turbines to improve the resistance to hot corrosion and high-temperature oxidation, in order to prolong the working life of components. These are diffusion coatings and diffusion coatings coated with ceramic coatings. The Ni22Cr10Al1Y coating is used on components such as blades and other gas turbine parts as the protection against hot corrosion and high-temperature oxidation up to 1100°C (Material Product Data Sheet, 2012, Nickel Chromium Aluminum Yttrium (NiCrAlY) Thermal Spray Powders, Amdry 9624, DSMTS-0102.0, Sulzer Metco). The chemical composition of the Ni22Cr10Al1Y coating should be compatible with the substrate material to reduce inter-diffusion during operation. Aluminum is an element which protects Ni alloys from oxidation up to 1200°C by forming oxide phases α-Al_2O_3 on the coating surface. The microstructure of vacuum plasma sprayed Ni22Cr10Al1Y coatings consists of the γ-Ni and β-(NiAl) phases (Feuerstein, et al, 2008, pp.199–213), (Padture, et al, 2002, pp.280-284). In the microstructure, there are also present γ'-(Ni_3Al) precipitates in γ-Ni(Cr) grains (Ma, et al, 2010, pp.1518–1529). The γ'-(Ni_3Al) precipitates in the M22Cr10Al1Y alloy provide better mechanical properties at temperatures below the solvus temperature, which is typically between 800 and 980°C (Achar, et al, 2004, pp.272–283), (Ma, et al, 2010, pp.1518–1529), (Mendis, Hemker, 2008, pp.255–258). The phases existing in the coating in the etched condition differ by color. The light gray regions in the coating microstructure are γ-Ni(Cr) grains which contain γ'-Ni_3Al precipitates, and the β-NiAl phase is dark gray. The differences in the microstructure between the APS and the VPS coatings are caused by higher temperatures of vacuum plasma spraying which increase the cohesive strength of lamellae and reduce the amount of oxygen in the environment,

thereby preventing oxidation of molten particles. In the coating layers, there are no oxides of the types: α-Al_2O_3, Cr_2O_3, NiO and $NiCr_2O_4$, which occur in coatings deposited by the APS process (Mrdak, 2012, pp.182-201), (Mrdak, 2013, pp.26-47). When MCrAlY coatings are applied, it is known that there is an interaction between MCrAlY coatings with the substrate, which is negligible during the thermal spraying in comparison with coatings in exploitation. The thermal stability of sprayed coatings is decreased with increasing the working temperature of the gas turbine. The inter-diffusion degradation becomes important with the temperature increase. The interaction between the coating and the substrate of superalloys was tested by the author (Gómez-Acebo, et al, 2004, pp.237-251), (Dahl, et al, 2006, pp.pp.73-78), (Yuan, et al, 2014, pp.63–69), (Liu, et al, 2015, pp.63–69). The coating diffusion provides enrichment of the substrate surface with aluminum and chromium and a higher tensile bond strength. After the VPS deposition of MCrAlY coatings, thermal treatment is applied. The aim of the thermal treatment of the deposited coating with the substrate is to strengthen the coating by thermal precipitation of fine intermetallic γ'-Ni_3Al compounds in the grains of solid γ-Ni(Cr) solution and the grains of the β-NiAl phase which increase the resistance of the coating to high-temperature creep together with the substrate. Due to diffusion bonding, the tensile bond strength of the coating significantly increases. The diffusion coating-substrate bonding occurs in the temperature range of 900 - 1150°C. Examinations have shown that the microstructure of the MCrAlY coating thermally processed at 1000°C for 1 hour and then cooled with argon to the room temperature for 15 min consists of a γ- solid solution rich in Ni, Co and Cr, which contains the dispersed phases of β-NiAl and γ'-$(Ni,Cr)_3$ (Funk, et al, 2011, pp.2233-2241), (Tang, et al, 2006, pp.94–106). In case of the Ni22Cr10Al1Y coating, vacuum deposited on the substrate of the 1N738LC nickel alloy, and after thermal processing in vacuum at a temperature of 1100°C for 2 hours, its microstructure shows the presence of fine globular particles of the β-NiAl phase (dark gray) and uniformly distributed in the matrix of γ-Ni(Cr) + γ'-Ni_3Al which is light gray (Funk, et al, 2011, pp.2233-2241). Due to the diffusion of Al and Cr from the coating in the substrate, the coating/substrate interface shows a diffusion zone consisting of the light gray γ-Ni(Cr) matrix that contains γ'-Ni_3Al precipitates of the deposited β-NiAl compounds (in black). Because of the diffusion of chemical elements from the substrate, the lower layers of the coating contain the elements Ni and Ti which build fine γ'-$Ni_3(Al,Ti)$ precipitates with aluminum (Itoh, Tamura, 1999, pp.476-483), (Gómez-Acebo, et al, 2004, pp.237-251), (Dahl, et al, 2006, pp.73-78).

The aim of this study was depositing a vacuum plasma sprayed (VPS) coating of the Ni22Cr10Al1Y alloy for the protection of gas turbine engine components against high-temperature corrosion and oxidation. In order to increase the resistance of the coating to high-temperature creep together with the substrate, thermal treatment was performed at 1100°C for 2 hours in a protective atmosphere of argon. The aim was to thermally deposit fine precipitates of γ'-Ni_3Al (which strengthen the coating) into the grains of the solid solution γ-Ni(Cr) and the grains of the β-NiAl phase. After the thermal treatment, the mechanical properties of the coatings in the deposited condition were analyzed as well as the microstructure of the layers of the coatings in the deposited condition. The coating quality was assessed afterwards.

Materials and experimental details

Coatings were produced from AMDRY 9624 powder which protects the substrate from high temperature oxidation and hot corrosion at temperatures t ≤ 1050°C (Material Product Data Sheet, 2012, Nickel Chromium Aluminum Yttrium (NiCrAlY) Thermal Spray Powders, Amdry 9624, DSMTS-0102.0, Sulzer Metco).

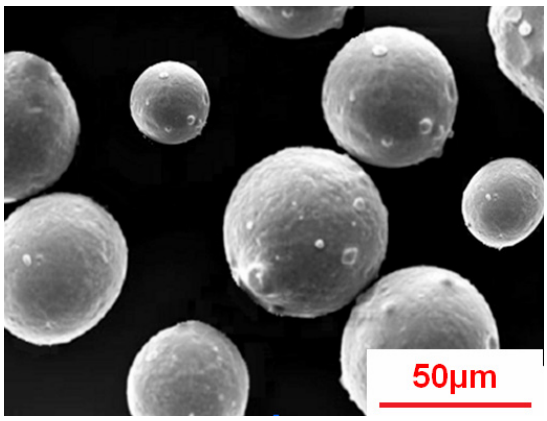

Figure 1 – (SEM) Scanning electron micrography of Ni22Cr10Al1Y powder particles
Рис. 1 – (SEM) Электронная микрография частиц порошка Ni22Cr10Al1Y
Слика 1 – (SEM) Скенинг електронска микрографија честица праха Ni22Cr10Al1Y

NiCrAlY powder is a nickel alloy with 22wt.%Cr, 10wt.%Al and 1wt.%Y with a range of powder particle granulation of 11 - 37µm. For the powder production, the vacuum furnace melting technique was used as

well as gas atomization of liquid melt with inert argon gas. The produced powder particles are homogeneous and spherical, Figure 1.

For microhardness testing and evaluation of the coating microstructure, the base was made of steel (X15Cr13 EN10027), thermally unprocessed, with the dimensions: 70x20x1.5mm. For testing the coating bond strength, the base was made of the same steel with the dimensions: Ø25x50 mm (Turbojet Engine – Standard Practices Manual PN 582005, 2002, Pratt & Whitney, East Hartford, USA). For testing the coating microstructure after heat treatment, the samples were made of an INCONEL X-750 alloy with the dimensions: 20x10x5 mm.

The mechanical properties of the layers were examined using the microhardness method $HV_{0.3}$ and their bond strength was examined with tensile testing (Turbojet Engine – Standard Practices Manual PN 582005, 2002, Pratt & Whitney, East Hartford, USA). The morphology of powder particles was examined by the SEM method. The microstructure of the coating layers in the deposited state and after heat treatment in the etched state was tested with light microscopy. The coating etching was done by mixing 2.5ml of nitric acid HNO_3 with 7.5ml of hydrofluoric acid HF.

Ni22Cr10Al1Y powder was deposited at low pressure with a vacuum plasma spray system of the Plasma Technik AG company. The control panel A-2000 and the plasma gun F4 were used for the powder deposition. Powder deposition was done with a mixture of plasma gases Ar/H_2. Before powder deposition, the surface of the INCONEL X-750 alloy substrate was cleaned and pre-heated with a transferred arc at a temperature of 850°C. Table 1 presents the VPS parameters for cleaning the substrate surface and depositing Ni22Cr10Al1Y powder. The thickness of the coating deposited on the substrates ranged from 150-200 μm. The coating deposited on the substrate of INCONEL Alloy X-750 was thermally treated at 1100°C in a protective atmosphere of argon for 2 hours.

Table 1 – Vacuum plasma spray parameters
Таблица 1 – Параметры ваккумного плазменного напыления
Табела 1 – Вакуум-плазма-спреј параметри

Parameters	Values	
	Cleaning arc	Spraying
Plasma current, I (A)	500	700
Plasma Voltage, V (V)	65	58
Primary plasma gas flow rate Ar (l/min)	50	50
Secondary plasma gas flow rate $He^{(1)}$,$H_2^{(2)}$ (l/min)	10 (1)	8 (2)
Carrier gas flow rate (l/min)	--	3
Powder feed rate (g/min)	--	40

Parameters	Values	
	Cleaning arc	Spraying
Stand-off distance (mm)	270	270
Chamber pressure (mbar)	25	150
Nozzle diameter (m m)	8	8
Speed of the gun (mm /s)	20	250

Results and discussion

The mean value of the microhardness of Ni22Cr10Al1Y layers was 198 $HV_{0.3}$. The lower value of the microhardness of the VPS Ni22Cr10Al1Y coating compared to the APS coating is caused by the absence of oxygen in the vacuum chamber, which prevents oxidation of molten particles in the deposition process. Low microhardness values confirm that in the coating deposited at low pressure there are not present α-Al_2O_3, Cr_2O_3, NiO and $NiCr_2O_4$ oxides which increase the value of the microhardness of coatings deposited at atmospheric pressure (Mrdak, 2012, pp.182-201). Besides the absence of oxidation in vacuum, low pressure of Ar inert gas allows preheating of the substrate up to 850°C, which leads to a substantial increase in adhesive bond strength. Tests have shown that the VPS-Ni22Cr10Al1Y coating has a bond strength of 84 MPa. Preheating the substrate and a low pressure of inert gas in the vacuum chamber further increase the coating density by eliminating micro pores and unmelted particles, as confirmed by the analysis of the coating microstructure on the light microscope. It is known that oxides and micro pores on the lamellae boundaries weaken the inter-lamellar bond, ie. cohesive strength and adhesion strength of the coating bond. Tensile strength testing has established that the failure mechanism was purely adhesion at the substrate / coating interface.

Figure 2 shows the microstructure of the VPS-Ni22Cr10Al1Y coating. The qualitative analysis showed that the substrate/ coating interface cannot be noticed because of cleaning and pre-heating the substrate surface with a transferred arc. The substrate/coating interface does not show defects such as: discontinuity of deposited layers, micro and macro cracks, micro and macro pores and separation of the coating from the base. The coating is dense and in the coating layers there are no: oxide lamellae, micro pores, precipitates, and unmelted particles. To see the microstructure of the coatings in the deposited state, Figure 3 shows a photomicrograph of the coating in the etched state. In the VPS Ni22Cr10Al1Y coating,

oxides and micro-cracks are completely suppressed, which resulted in an even and uniform deposition of layers.

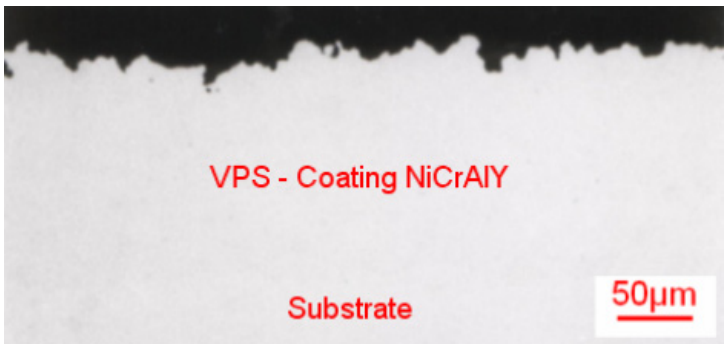

Figure 2 – (OM) micrograph of the vacuum plasma sprayed Ni22Cr10Al1Y coating
Рис. 2 – (OM) микрография вакуумного плазменного напыления *Ni22Cr10Al1Y*
Слика 2 – (OM) Микрографија вакуум-плазма напрскане превлаке Ni22Cr10Al1Y

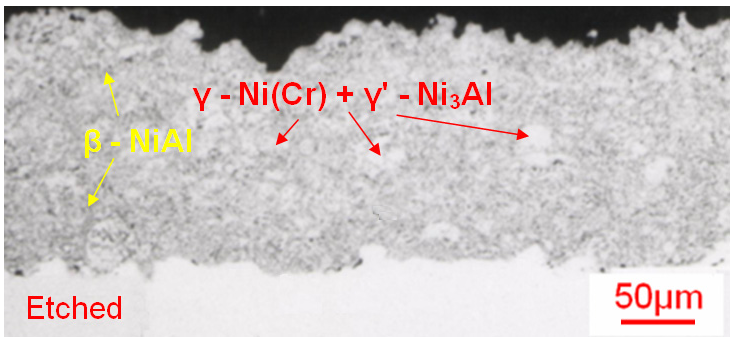

Figure 3 – (OM) Etched microstructure of the vacuum plasma sprayed Ni22Cr10Al1Y coating
Рис. 3 – (OM) Поврежденная микроструктура покрытия, нанесенного вакуумным плазменным напылением Ni22Cr10Al1Y
Слика 3 – (OM) Нагризена микроструктура вакуум-плазма напрскане превлаке Ni22Cr10Al1Y

Due to high temperature of the substrate and a complete melting of the layer deposited with the previously deposited layer, the lamellar microstructure in the coating completely disappeared. Coating etching makes two phases recognizable in the microstructure, one of which is light gray and the other is dark gray. The main phase of the coating (light gray) is the solid solution γ-Ni(Cr), which provides coating ductility and contains fine γ'-Ni_3Al precipitates while the dark gray β-NiAl phase provides resistance to oxidation (Funk, et al, 2011, pp.2233-2241). The coating microstructure

shows more regular melting of powder particles in vacuum relative to the atmospheric pressure.

Figure 4 shows a photomicrograph of a largely magnified coating to see the coating microstructure more clearly.

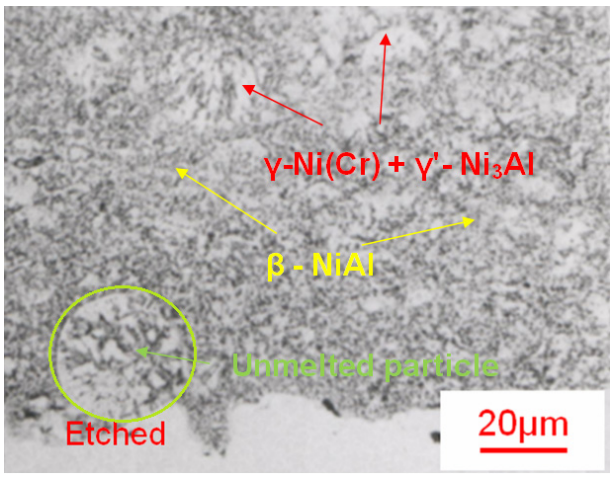

Figure 4 – (OM) Etched microstructure of the vacuum plasma sprayed Ni22Cr10Al1Y coating
Рис. 4 – (ОМ) Поврежденная микроструктура покрытия, нанесенного вакуумным плазменным напылением *Ni22Cr10Al1Y*
Слика 4 – (ОМ) Нагризена микроструктура вакуум-плазма напрскане превлаке Ni22Cr10Al1Y

Light gray regions of the solid γ-Ni(Cr) solution with γ'-Ni3Al precipitates are clearly seen as well as the dark gray region of the β-NiAl phase. The substrate/coating interface shows one unmelted powder particle of 25μm which is fully united with the deposited coating layers. The presence of the unmelted particle did not affect the formation of pores in the coating around it.

After heat treating the coating in vacuum in order to strengthen the deposited layers by thermal precipitation of intermetallic γ'-Ni_3Al compounds, the coating is more homogeneous with respect to the deposited state (Figure 5). Homogeneity is a consequence of the increased solubility of Al in the γ phase at a temperature of 1100 °C. During the heat treatment of Al and Ti, γ' intermetallic compounds $Ni_3(Al,Ti)$ are formed with Ni from the substrate, thus enhancing the coating and increasing its resistance to high temperature creep, together with the substrate.

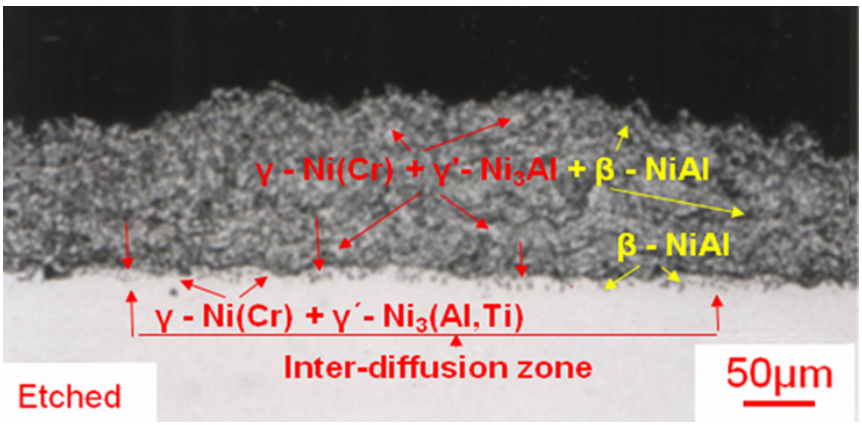

Figure 5 – (OM) Etched microstructure of the Ni22Cr10Al1Y coating after heat treatment at 1100°C/2 hours
Рис. 5 – (OM) Поврежденная микроструктура покрытия Ni22Cr10Al1Y после термической обработки при 1100°C/2часа
Слика 5 – (OM) Нагризена микроструктура превлаке Ni22Cr10Al1Y после термичког третмана на 1100°C/2 сата

After heat treatment under vacuum at a temperature of 1100 °C for 2 hours, the microstructure of the Ni22Cr10Al1Y coating shows globular particles of the β-NiAl phase (dark gray), evenly distributed in the γ-Ni(Cr) + γ'-Ni_3Al matrix (light gray) (Funk, et al, 2011, pp.2233-2241). It is clearly visible that an inter-diffusion zone is formed on the inter-surface. Because of the dominant diffusion of Al and Cr from the coating into the substrate, a zone enriched with the β-(NiAl) phase was formed on the interface in the substrate. The diffusion layer was formed of the NiCr matrix (light gray) and the deposited β-NiAl compounds (black). Because of the diffusion of Al into the substrate, the Al content is reduced in the coating. Substantial precipitates of the β-NiAl phase are woven in the diffusion zone which is in the base of the INCONEL X-750 alloy. Also, Ti from the substrate diffuses into the lower layers of the coating where it participates with Al in the formation of intermetallic γ'-Ni_3(Al,Ti) compounds (Itoh, Tamura, 1999, pp.476-483), (Gómez-Acebo, et al, 2004, pp.pp.237-251). The thickness of the diffusion zone formed of the γ-Ni(Cr) solid solution with precipitates and the β-(NiAl) phase on the coating / substrate interface is 20μm.

Conclusion

In this paper, vacuum plasma spraying is used to deposit Ni22Cr10Al1Y coating layers. The paper analyzes the mechanical properties and the microstructure of the coatings in the deposited state and after thermal treatment of the coating at 1100 °C in a protective atmosphere of argon for 2 hours. The following was concluded:

The VPS Ni22Cr10Al1Y coating had a mean microhardness value of $198HV_{0.3}$. The value of the VPS Ni22Cr10Al1Y microhardness is lower compared to the same coating deposited at atmospheric pressure due to the low pressure of Ar inert gas in the vacuum chamber, which prevented the oxidation of molten particles in the deposition process.

The tensile bond strength value of the VPS Ni22Cr10Al1Y coating deposited in vacuum was 84 MPa and is higher than the bond strength of the same coating deposited at atmospheric pressure. The tensile bond strength is higher because inter-lamellar oxides and micro pores are completely suppressed in the coating, which has led to higher inter-lamellar strength and stronger adhesion of the coating to the substrate.

The microstructure of the Ni22Cr10Al1Y coating in the deposited state after etching in the reagent consists of the basic phase of the solid solution of chromium in nickel γ-Ni(Cr) (light gray) which contains fine precipitates of γ'-Ni_3Al and the β-NiAl phases (dark gray). The mirostructure of the Ni22Cr10Al1Y coating is homogeneous after heat treatment in vacuum. In the microstructure of the etched coating there are globular particles of the β-NiAl phase (dark gray) evenly distributed in the base of the γ-Ni(Cr) + γ'-Ni_3Al coating (light gray). At the interface, a 20μm-thick inter-diffusion zone was formed in the substrate. Because of the dominant diffusion of Al and Cr from the coating in the substrate, the zone enriched with the β-(NiAl) phase is present in the substrate at the interface. The diffusion layer is formed from the γ-Ni(Cr) matrix (light gray) and the deposited β-NiAl compounds (black). Because of diffusion, Ti from the substrate in the lower coating layers participates with Al in the formation of intermetallic $Ni_3(Al,Ti)$ compounds. The formed diffusion layer and deposited intermetallic compounds in the coating increase its resistance to high-temperature creep along with the substrate.

The VPS Ni22Cr10Al1Y coating has a much better structure and mechanical properties compared to the properties of the coating deposited at atmospheric pressure and as such can successfully be applied in hot

sections of turbojet engines to protect them against high-temperature oxidation and corrosion.

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СТРУКТУРА И СВОЙСТВА ПОКРЫТИЯ Ni22Cr10Al1Y НАНЕСЕННОГО МЕТОДОМ ВАКУУМНОГО ПЛАЗМЕННОГО НАПЫЛЕНИЯ

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Резюме:

В данной статье описан процесс нанесения покрытия Ni22Cr10Al1Y вакуумным плазменным напылением для защиты деталей газотурбинного двигателя от оксидирования и высокотемпературной коррозии. Покрытие может оказать значительное воздействие на свойства субстрата, так как вместе с ним создает композит.

Течение процесса депозиции покрытия и режим термической обработки с субстратом значительно влияют на стойкость слоев покрытия к высокотемпературной ползучести.

Нанесение порошка Ni22Cr10Al1Y произведено аппаратом вакуум плазменного напыления от производителя Plasma Technik – AG, включающим пульт управления A-2000 и плазматрон F4. Покрытие нанесено на субстрат сплава INCONEL X-750, затем произведена двухчасовая техническая обработка при 1100^{0}C в защитной среде аргона. Морфология частиц порошка испытана методом оптической микроскопии. Анализ механических характеристик покрытия проведен на основании испытаний микротвердости методом $HV_{0.3}$ и прочности соединений методом растяжения. Микротвердость покрытия соответствуют требованиям стандартов Pratt & Whitney. Микроструктура слоев нанесенного покрытия испытана методом световой микроскопии. Повреждения покрытия вызваны раствором азотной кислоты 2.5ml HNO_3 с 7.5ml плавиковой кислоты.

Анализ микроструктуры повреждений покрытия до и после термической обработки, а также толщины диффузной части проведен методом световой микроскопии, на основании результатов анализа дана оценка качества покрытия.

Ключевые слова: вакуум, субстраты, структурные свойства, плазма, слои, покрытие.

СТРУКТУРА И СВОЈСТВА ПРЕВЛАКЕ Ni22Cr10Al1Y ДЕПОНОВАНЕ ВАКУУМ-ПЛАЗМА-СПРЕЈ ПРОЦЕСОМ

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Сажетак:

Циљ рада јесте да се вакуум-плазма-спреј процесом депонују слојеви превлаке Ni22Cr10Al1Y за заштиту компоненти гасних турбина од оксидације и високотемпературне корозије. Превлака може знатно утицати на својства субстрата, јер заједно са субстратом формира композит. Врста процеса депозиције превлаке и режим термичке обраде превлаке са субстратом битно утичу на њену отпорност на високотемпературно пузање. Депоновање праха Ni22Cr10Al1Y урађено је вакуум-плазма-спреј системом фирме Plasma Technik – AG који користи командни пулт A-2000 и плазма пиштољем F4. Превлака депонована на субстрату од легуре INCONEL X-750 термички је обрађена на 1100^{0}C у трајању од 2 сата у заштитној атмосфери аргона. Морфологија честица праха испитана је методом скенинг електронске микроскопије. Испитивања микротврдоће слојева рађена су методом $HV_{0.3}$ и чврстоће споја методом испитивања на затезање, која су била у складу са стандардом Pratt & Whitney. Микроструктура слојева превлаке у депонованом стању испитана је на светлосном микроскопу. Нагризање превлаке рађено је мешањем азотне киселине 2,5 ml HNO_3 са 7,5 ml флуороводоничне киселине HF. Анализа микроструктуре нагризене превлаке пре и после термичке обраде, као и дебљина дифузионе зоне, изведена је на светлосном микроскопу, на основу чега је оцењен квалитет превлаке.

Кључне речи: вакуум, субстрати, структурна својства, плазма, слојеви, превлаке.

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EXPERIENCE IN DEVELOPING AN INNOVATION IN VIEW OF ITS SCIENTIFIC VERIFICATION AND THE PRODUCT PLACEMENT ON THE MARKET

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Abstract:

The paper presents an innovative device for dismantling and assembling parts of not-easily detachable assemblies of mechanical and electrical plants for on-site overhaul. The novelty is that the device offers fast and efficient dismantling and assembling of parts, without the possibility of damage. It is easy to use and easy to carry. It is used for all types of plants and higher levels of overhaul in field conditions. This quality device has been in the market for 4 years. The device is expected to be used over the next 10 years, and probably longer. Many years of experience in solving maintenance and repair problems resulted in this device for dismantling and assembly of mechanical and electrical assemblies. Many assemblies could not be dismantled and assembled in field conditions. The new device enabled developing a new technology of on-site overhaul and new methods of organization work and overhaul execution. It took only six months from an idea to its implementation due to producer's extensive experience in these and similar jobs. This innovative device is sold with the contractual obligations regarding the protection of the confidentiality of its construction and application.

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The device is in the process of obtaining patent rights from the Intellectual Property Office in Belgrade, and after that it will be filled as an international patent application to the PCT.

Key words: innovation, new device, dismantling and assembly, not-easily detachable assemblies, overhaul, mechanical and electrical plants, mini hydro power plants, shipbuilding, military industry, business model, innovative company, techno-economic analysis.

Introduction

An innovative product, a complete device for dismantling and assembling parts of not-easily detachable assemblies on mechanical and electrical installations during on-site overhaul, is a new and original product in the country and the world. Research and development have been done as well as design, testing in the laboratory conditions and checking the functionality under field conditions in accordance with the requirements of the customer. Verification has been finished together with the certification and homologation of the system for the purpose of its application (Žegarac, 2012a). All device components met the required standards in the domestic and foreign markets (Žegarac, 2012b).

This new device for disassembling and assembling parts of not-easily detachable assemblies solves many problems in the field overhaul conditions. It is used for a higher level of overhaul in field conditions: intermediate level overhaul, general revision and general overhaul. Until now, in the country and the world, assemblies have been transported to specialized workshops or technical overhaul institutes for higher-level overhaul. In addition, existing devices are not applicable under field conditions on mechanical plants of different manufacturers. All this makes repairs significantly more expensive, up to 50%, compared to the value of the overhaul itself. Operating systems are not in use for a long time, which causes significant production losses.

The universal new device can be used in many mechanical and electrical assemblies of various manufacturers, which is its main feature and advantage compared to the existing systems of a conventional type. The overhaul time is now significantly reduced, even up to 2 months if a general system overhaul is carried out (Tehnička dokumentacija firme Flender, 1975), (Tehnička dokumentacija za MHE, 1980).

The innovative device has enabled the development of a new, on-site overhaul technology, new ways of working in the organization and overhaul execution (Žegarac, 2012), (Žegarac, 2013). The device has been on the market for 4 years. Twenty sets have been delivered so far. The new

device for dismantling and assembly has a wide range of applications: mechanical engineering, energy, automotive, shipbuilding, ship and vessel repair, aircraft industry, process industry, private firms that perform system maintenance and other industries. Potential market is not saturated. It is estimated that about 5.000 sets of various tools from over 80 manufacturers in the world are used to carry out overhaul. Such tools are not effective in field conditions. There is a continuous need to purchase high-quality devices and equipment. It is expected that, in the next 5 years, the sales of the new device will increase for 200 to 300 sets. In addition to purchase, customers often engage the manufacturer of this innovative product to make a higher level of service repair, which represents a significant inflow of profits for the company. Additional delivery of 30 sets is planned in 2017. Customers are electro industry, private companies and steel producers. The plan is to sell at the market of the Republic of Serbia, for the needs of the Electric Power Industry of Serbia (EPS) and several private companies. Years of experience in sales, application of the device for dismantling and assembling parts of not-easily detachable assemblies and providing overhaul services have helped in recognizing customer requirements.The innovative company can perform all forms of on-site overhaul. Customers are very satisfied with customer care and personal support. Selling a dismantling and assembly device is performed through the *Know-How* system.

Customers are mainly contacted in the public and on sites. So far, there have been no complaints regarding the new device and the repair service. The company possesses the necessary technical, financial, intellectual, market and human resources for the job. It has more than 30 years of professional experience. Key partners produce high-quality components to customers' satisfaction. The company has a highly qualified and professional staff to perform all types of repair and overhaul. The company has 12 employees, out of whom three make a special team. One of them is an academic, patent engineer, engaged in research and development and design of mechanical and electrical systems; as a team leader, he provides jobs on the market and cooperates with many companies. He participates actively during the overhaul of mechanical and electrical installations. He also performs the function of supervisory authority in the company affairs and monitors whether customers are satisfied with the quality of devices, installation and services. The second team member is a specialist for the repair of thermal power plants, hydro power plants, nuclear plants and other complex technical systems. He finished secondary school of mechanical engineering and secondary electro-technical school, has all authorizations and licenses to work in our country and abroad, overhauls mechanical and electrical systems and other complex systems. He mana-

ges the team that carries out repairs of plants. The third team member is an MSc specialized in the installation and repair of electric power systems, a specialist in electric power plants and control. He has all authorizations and licenses to operate in the country and abroad. He performs tasks as an electrical engineer. The team has demonstrated success in previous sales of the device and in providing services of technical maintenance of mechanical and electrical installations.

This innovative device solves numerous problems in repair both in field conditions and in specialized workshops. The innovative company builds its competitive advantage on simplifying the technology of higher level overhaul, increasing the quality and reliability of plants in operation and reducing overhaul cost and time by 50%. The possibility of damage to the parts during dismantling and assembly is excluded. The price of the dismantling and assembly device is acceptable to customers (6.000 Euros).

In the process of device production and delivery, the innovative company charges the value of the production materials in advance. The rest of the payment is made within 30 days upon delivery to the customer's warehouse. The profitability threshold is achieved by sales of 2 device sets (Petrov, 2016a). The first year of operation covered all costs. The business model is highly profitable, the level of security is such that the business model can withstand drastic market turbulences without any loss. The company is planning to deliver about 300 equipment sets at domestic and foreign markets over the next 5 years. All variable and fixed costs of the company are also covered.

Part I – Innovation

The novelty of the innovative device

This universal device enables overhaul of assemblies of different manufacturers in field conditions. It has a wide range of applications, which until now was not the case. The universality of the device in application is achieved through various combinations of its components, which does not mean that the number of components is increased, but it means that individual components are constructed and adapted to cover a variety of sizes and dimensions of many assemblies being overhauled.

Analysis of the current state of technical installations

Many owners of mechanical and electrical installations require that technical maintenance and repair be performed in their plants, which greatly complicates the work. Technical maintenance of systems includes activities in the area of operational (basic) maintenance, light repair, inter-

mediate repair, general overhaul and general plant overhaul. Operational maintenance and light repair are performed mainly by the users of the system. Many mechanical and electrical assemblies are transported to specialized workshops or overhaul depots for dismantling and reassembling parts being replaced. Almost 60% of assemblies could not be repaired on the spot. Besides, the transport of some assemblies is very complex, and there are many problems during loading and unloading, and security measures during transport. This used to consume a lot of time for system repair and maintenance, which significantly increased overhaul costs, in some cases up to 50%. In addition, there are significant losses in production since the plant is out of operation for a longer period, especially in cases such as hydro and thermal power stations and other production systems.

The innovative device for dismantling and assembling not-easily detachable mechanical and electrical assemblies has been adapted to field conditions providing that all aspects of maintenance and overhaul can be performed on site. This universal innovative device can be used for the repair of many mechanical and electrical installations of various manufacturers such as German companies: Flender, Siemens, Vulkan, Stromag, Ossenberg, Geislinger, AEG, FAG, SKF and many others. These companies are the largest manufacturers of assemblies for the systems of large hydro power plants and mini hydro power plants, where this innovative company provides services of technical system maintenance. These mechanical and electrical assemblies make a whole system, and it is therefore necessary to have such a device available.

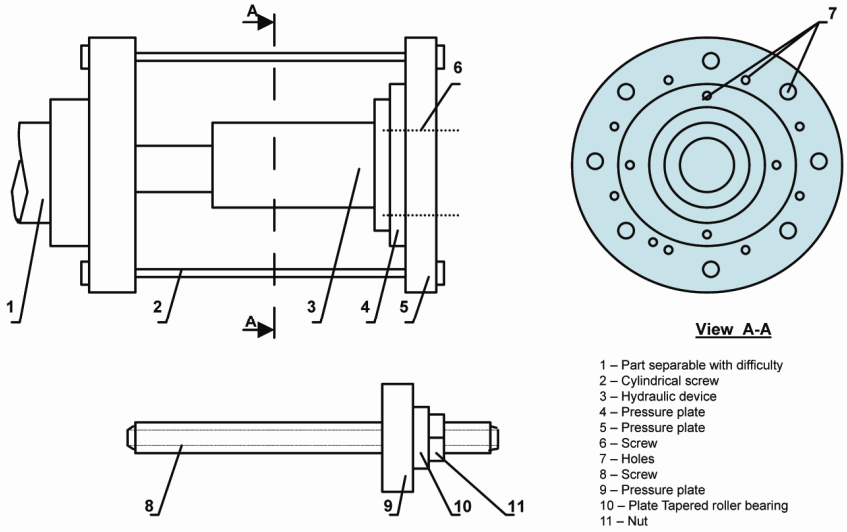
The innovative device is modular and can also be used in other types of plants. In the application of the device, the device elements are selected and combined, depending on the type and dimensions of components thus solving the overhaul problems. The device is easy to use and easy to carry. Systems for dismantling and assembling of domestic and foreign manufacturers do not have such characteristics. The main drawback of the existing devices is that they cannot be used in the field conditions. In addition, each manufacturer has adapted the dismantling and assembly of parts for their own plants, so they cannot be applied to plants of other manufacturers. Such systems are some kind of special tools, devices or equipment.

Innovative product and service

The unit of a new product is a set for dismantling and assembling mechanical and electrical assemblies. At the same time, buyers are provided with quality services and technical maintenance of the system. The

new device allows easy, fast, high-quality disassembly and assembly of parts of not-easily detachable mechanical and electrical assemblies, on the spot. The innovative device consists of 3 parts (Figure 1).

A - *Mechanical and hydraulic parts of the device*



B - *hydraulic components and units for device heating*

Figure 1 – Device for dismantling and assembling not-easily detachable mechanical and electrical assemblies

Рис. 1 – Монтажно-демонтажное устройство для сложно разбираемых узлов машиностроительного и электротехнического оборудования

Слика 1 – Приказ уређаја за демонатжу и монажу тешко растављивих машинских и електросклопова

The first part consists of mechanical components, the second part is a hydraulic unit and the third part is a unit for heating parts of mechanical and electrical assemblies which are dismantled and re-assembled. The device is used in all areas where mechanical and electrical assemblies are used. In electrical installations there are also built-in machine elements which after a certain period of exploitation should be replaced. For example, bearings of generators and electric motors, damaged covers and frames of assemblies, seals and many other parts of these plants. On several occasions since 2002, the innovative company has conducted, for the Electrical industry Montenegro, technical maintenance services based on overhaul plans at 18 mechanical and electrical plants: intermediate repair, general revision and overhaul. Within overhaul services, vibration analyses and vibration measurements were performed, as well as vibrodiagnostics, dynamic balancing of systems, laser alignment of assemblies, thermal imaging measurements (remote measurement of temperature at certain plant points) and others. The innovative company performs intermediate repair every 3 years in prescribed intervals, general revision every 4 years and overhaul after 6 years. Systems of mini hydro power plants are in continuous operation when there is sufficient water, i.e. in the period from late September to early June. In addition to regular overhaul activities, the company had to deal with damage to plants due to uncontrollable groundwater flows. Concrete foundations of assemblies broke resulting in major damage to assemblies.

Figure 2 presents the damage to a flange of flexible couplings ARPEX series K 430, size 270 mm on the flywheel shaft (right side in Figure 2), of the German manufacturer Flender. The flange was damaged due to inadequate removal. There were visible hammer blows and the distorted flange rim, which, during mini hydropower operation, causes elastic couplings to break with a possible breakdown of the entire system due to the dynamic unbalance and misalignment of the drive shaft.

Figure 3 presents a boken flange on the generator shaft of a mini hydro power plant due to improper dismantling and assembly of parts. Overhaul service had been carried out by companies not sufficiently specialized, professional and equipped to carry out complex overhaul tasks.

Figure 2 – Damage to the flange of flexible elastic couplings on the flywheel shaft of a mini hydro power plant
Рис. 2 – Изображение повреждений фланца упругой муфты на оси маховика мини-ГЭС
Слика 2 – Приказ оштећења прирубнице еластичне спојнице на осовини замајца мини-хидроелектране

Figure 3 – Broken flange of the elastic coupling on the mini hydro generator flywheel
Рис. 3 – Изображение сломанного фланца упругой муфты на оси генератора мини-ГЭС
Слика 3 – Приказ поломљене прирубнице еластичне спојнице на осовини генератора мини-хидролектране

Figure 4 presents a mini hydro power plant flywheel damaged due to inadequate removal. The lower wedge for a clamping screw on the underside of the flywheel (left side of Figure 4) was broken. The *"naked"* screw that has no tightening function can be seen. Huge damage was inflicted. Creating a new flywheel is very complex, expensive and time-consuming with a foreign manufacturer. Installing a new flywheel on a mini hydro power plant requires dynamic balancing and vibration measurements.

Figure 4 – Damaged flywheel of a mini hydro power plant
Рис. 4 – Изображение повреждений маховика мини-ГЭС
Слика 4 – Приказ оштећења замајца мини-хидроелектране

Figure 5 presents a high-quality assembly in the aggregate hall of a mini hydro power plant on the site, (view to right), using the new device for dismantling and assembling mechanical and electrical assemblies. A part of the assembly device and the device heating unit can be seen. A part of Flender couplings N-EUPEX type 480 is mounted on a new mechanical assembly, the drive shaft of the plant multiplier produced by Flender, Germany. The second half of the coupling is mounted on the turbine shaft of the hydro power plant.

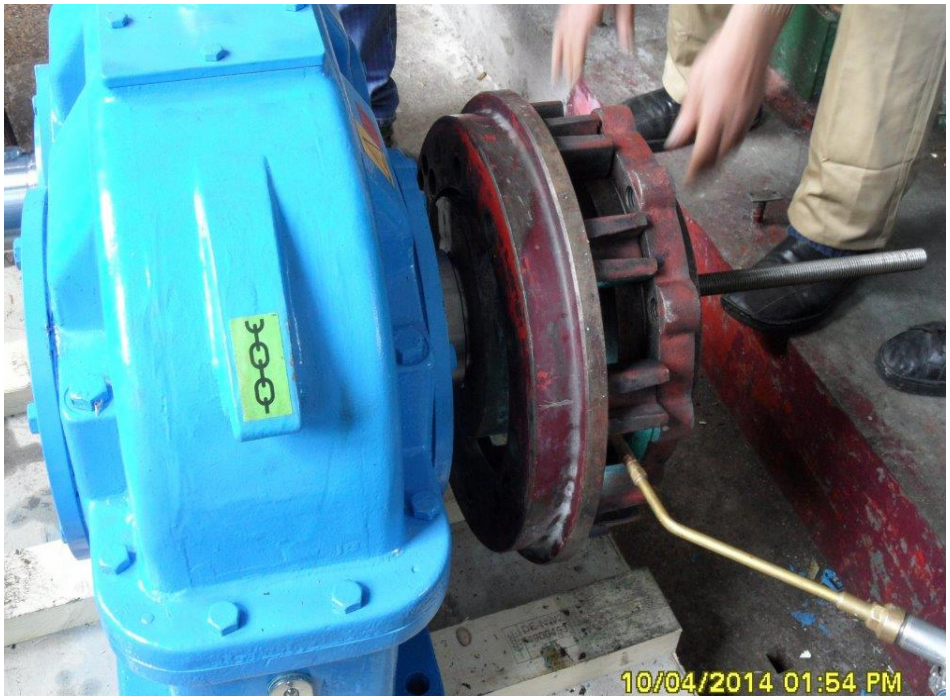


Figure 5 – High-quality installation of assemblies using the new device for dismantling and assembling
Рис. 5 – Изображение качественной сборки узлов с помощью нового монтажно-демонтажного устройства
Слика 5 – Приказ квалитетне монтаже склопова помоћу новог уређаја за демонтажу и монтажу

Previous sales and many offered services of technical maintenance of mechanical and electrical plants have proven successful use of the device. The appendix, *Business Model,* shows the Minutes on providing overhaul services in the Electrical industry Montenegro (Annex 1 and Annex 2).

Market potential of the innovation

Market size and market potential

The innovative device for dismantling and assembling has wide possibilities of application: power plants, thermal power plants, nuclear power plants, aviation industry, turbine systems in the process industry, ships, reciprocating compressors, gas turbines, automotive industry, internal combustion engines, diesel generator sets used as a backup source of

power supply, machine tools, steel mills, mines, and many other plants where it is necessary to install new mechanical elements, or dismantle assemblies for replacement of worn or damaged system parts. Potential customers of the innovative product and services are companies engaged in the production and technical maintenance of mechanical and electrical installations.

Potential customers are also owners of mechanical and electrical installations in mechanical engineering, energy systems, automotive industry, shipbuilding and repairs of ships and other vessels, steel mills, cement plants, process industry, technical overhaul institutes and many others.

There is a continuous need for the procurement of new devices and equipment. So far, customers have been buying systems with a variety of special tools, equipment and accessories for dismantling mechanical and electrical installations, which are not universal. Complex forms of plant maintenance were carried out in specialized workshops or technical overhaul institutes.

Such devices were more like toolkits. Sets of tools are strictly personalized - each plant has its own set of tools.

Tools can be used for operational maintenance and some works in the field of light repair. They did not meet the requirements and conditions of a higher overhaul level. It is estimated that there are around 5000 sets of tools currently used.

Works in ship repair are important in particular. There is limited space available for overhaul works. The propulsion systems of ships are especially challenging: diesel engines, gearboxes, various flexible couplings, replacement of the shaft bearings, or replacement of the shaft bearings on the propeller.

It is expected that sales could grow by 200 to 300 pieces of equipment sets for dismantling and assembly.

In its previous work, the innovative company was particularly involved in the systems of mini hydro power plants in the Electrical industry Montenegro. Twenty devices have been delivered, out of which 18 are in the system of maintaining mini hydro power plants and 2 devices are used in HPP Piva and HPP Perućica for the repair of water pumps.

Table 1 shows the placement of the new product, the market size and the market potential.

Table 1 – Market size and market potential
Таблица 1 – Размер рынка и рыночный потенциал
Табела 1 – Величина тржишта и тржишни потенцијал

For the needs of electroindustry, large hydropower plants, mini hydropower plants and pumping plants	For the needs of electroindustry-thermal power plants and pumping plants	For the purposes of shipbuilding, repair of ships and other vessels	For the needs of automotive industry, process and aerospace industries, cement factories, mines and other customers	For the needs of other customers: utilities public enterprises, technical-overhaul institutions and other customers
100 sets of equipment	60 sets of equipment	70 sets of equipment	40 sets of equipment	30 sets of equipment

Competition analysis

On the domestic market and the market of the neighboring countries, there are reputable companies, manufacturers of mechanical and electrical systems, such as Siemens, AEG, Flender, Stromag, Geislinger, Voith Andreas, Uljanik Pula, and Rade Končar Zagreb. Manufacturers of mechanical and electrical plants produce their special systems, accessories, tools and equipment for dismantling and installation of assemblies from their manufacturing programs, which are not applicable to plants of other manufacturers. In addition, such systems are not sufficiently adapted and applied to field conditions, which is their main disadvantage. Some manufacturers have developed systems for technical maintenance and repairs on the principle of aggregate replacement of complete mechanical and electrical assemblies. This means that they deliver new or overhauled mechanical assemblies to the customer, where the need arises. They take over the complete existing assembly from the client and overhaul it, for extra charge. The innovative device solves the problems of competition (Petrov, 2016a).

The innovative company has gained the trust of customers. Very often it is engaged by foreign manufacturers of devices and equipment to carry out the installation of new devices or overhaul of existing circuits at the user's facility. The innovative company has a personal support and direct relationships with purchasers and service recipients. It is very fast to react on the ground and resolve the existing problems within 24 hours. Additionally, it acts preventively to avoid early failures and system crashes.

The innovative company provides training to technical staff responsible for the correct plant operation. It develops plans for current and regular technical maintenance. All this provides the innovative company with a huge advantage when participating in public tenders for obtaining jobs.

Part II - Business model

Target customers in 2017

Target customers of the innovative device for dismantling and mounting assemblies for 2017 are: Electrical industry Montenegro, owners of commercial, passenger ships, cruise ships, war ships and ships carrying cargo (barges) and several private companies that provide services in the field of technical system maintenance.

For the purposes of the Electrical industry Montenegro (EPCG), the innovative company needs to supply an additional quantity of 17 sets of equipment for dismantling and assembly. The customer wants to have the devices at all locations where their plants are located. The locations of their systems are quite distant from one another. The other 13 sets of equipment are to be delivered to private companies engaged in overhaul of diesel generating sets, pump plants in the field and to owners of ships and vessels. There is also some interest from the steel mills and cement factories from neighboring countries.

Description of the offer value to targeted customers

Since this new product, a device for assembling and dismantling not-easily detachable equipment sets, has been on the market for a long time, it is fully known what new customers want and what they need. Their request for overhaul is to be performed on the plant site, to be of good quality, and with no damage to parts and assemblies. This innovative technology significantly reduces the price of the overhaul for 50% of the total overhaul price, which is very important for customers. The buyer has much higher costs if mechanical or electrical assemblies are disassembled, transported and overhauled at some Overhaul Institute and returned to the facility for installation. The price of the entire device is 6.000 Euros. In addition, the customer does not have high device maintenance costs. Additionally, the customer gets free on-site training of technical staff to be able to perform some simple repairs on their own, which is sometimes very important.

Sales channels to target customers

So far, the innovative company has had direct relationships and personal support from customers for the sale of the new device for dismantling and mounting assemblies, a Know-How based-system. The company participated in published public tenders. The tender documentation was not only about the requirement of the lowest price but also about the quality of overhaul, duration of the execution of works and many other parameters. On that basis, the innovative company has always won contracts to mutual satisfaction. This significantly has contributed to the increased reliability of technical devices and systems (Šenk, 2016).

Relations with target customers

Relationships with customers are maintained through a personal support system. The company has direct relations with many customers, which proved to be the best way of cooperation (Rašković-Depalov, 2016). They have no significant costs in contacts with customers. They retain their customers with responsibility and professionalism. Customers expect to get a high-quality device (no complaints up to now) with quality repair services on site. If there are any unforeseen failures, the innovative company comes quickly to the site to solve the problem.

Based on years of experience and real needs, the innovative company proposes the specification of spare parts. Many spare parts are imported and foreign suppliers sometimes need considerable time to deliver their goods.

Bearing all this in mind, customers appreciate the planned activities of this innovative company and keep it in their operational systems. Service costs are quickly paid by the buyer.

Revenues

The innovative copany sells the finished product, a device for dismantling and installation and provides technical maintenance services to target customers. The revenue projections for the twelfth month are shown in Table 2. There are no restrictions on the production and service capacities. Customers accept the price in full (Ćelić, 2016).

Table 2 – Projected revenues in the twelfth month
Таблица 2 – Прогнозируемые доходы в XII месяце
Табела 2 – Пројекција прихода у XII месецу

PRODUCT / SERVICE	MONTHLY SALE	SALES PER PIECE	TOTAL REVENUE
	Pcs	(Currency) €	Currency) €
A	3 sets of devices	6.000	18.000
B	1 technical maintenance service	12.000	12.000
IN TOTAL			30.000

Key resources

The innovative company has technical, financial, intellectual, marketing and human resources. It has more than 30 years of professional experience. In the work organization, the manufacturers of the components of the device for dismantling and assembling mechanical and electrical assemblies are very important. They are required to deliver device components of high quality. The new device as an innovative product was developed a few years ago, tested and put to use, which is proved by appropriate technical documentation on the development, design and quality of the device.

The innovative company has highly qualified and professional people to perform overhaul services. Professionals have a number of licenses and authorizations to work. Repair services are specifically agreed upon, depending on the type of plants, the scope of work, quantity of spare parts, locations of the facility, etc.

The description of the key resources is shown in Table 3 and Table 4 (investments to start the business).

Table 3 – Description of the key resources: Team, intellectual property and material resources
Таблица 3 – Описание основных ресурсов: Команда, интеллектуальная собственность и материальные ресурсы
Табела 3 – Опис кључних ресурса: тим, интелектуална својина и материјални ресурси

DESCRIPTION OF THE TEAM	Innovative team consists of: 1. Academic, patent engineer, working on research and development, design, mechanical and electrical systems, 2. Specialist for overhauling thermal power plants, hydro power plants, nuclear power plants and other complex technical systems, 3. Master of Science, a team of specialists in the installation and repair of electric power systems, a specialist in power plants and control.

INTELLECTUAL PROPERTY	Device for dismantling and installation, after sales system Know-How. The company intends to apply for patent protection, and after that to go to the PCT protection. The innovator has 5 world-recognized patents in the field, he is the author of over 90 scientific papers published in national and international journals of the highest category. He participated in many scientific conferences in the country and abroad. He has worked on many projects and scientific studies. Intellectual property and human resources support their business model.
TECHNICAL RESOURCES	The innovative company has capacity to produce devices for dismantling and assembly that can meet all customer needs. The subcontractor for the production of the mechanical component of the device is Jeep Commerce Belgrade (delivery of quality materials), high-quality machining is performed by Alatnica Lazarevic Belgrade, and Nitro Jon company, Stara Pazova, perform thermo-chemical processing of machine parts. The hydraulic component of the device is performed by Sloga company, Nova Varos, while alternative suppliers are companies Lincos from Hungary, and Womax and Einhell from Germany. The unit for heating device parts is supplied by the firm Teleoptik, Zemun. The innovative company is specialized in performing a variety of services of technical maintenance. They are equipped with special tools, fixtures, appliances and other equipment. They also have official motor vehicles for the transport of the team, parts and tools to the field.
MARKET RESOURCES	In the last four years, they have sold 20 devices. In agreement with our customers the plan is to sell another 30 sets of equipment in the current year, following the production plan and delivery schedule.
FINANCIAL RESOURCES	Innovative company achieves significant inflows by selling the device for dismantling and installation, and by providing quality services of technical system maintenance. The expected cash at the end of the period amounts to 120,030 Euros, covering all the costs of the business.

Table 4 – Description of the key assets: Investments to start the business
Таблица 4 – Описание основных активов: Инвестиции в запуск бизнеса
Табела 4 – Опис кључних ресурса: инвестиције за почетак пословања

TYPE OF INVESTMENT	DESCRIPTION OF INVESTMENT	Amount in €
Fixed assets	Investments whose effect is expected in the period> 1 year	
• Intangible assets	Investments in the development of products / services Investments in concessions, patents, licenses and similar rights	1.500

TYPE OF INVESTMENT	DESCRIPTION OF INVESTMENT	Amount in €
• Real Estate	Investments in land Investments in facilities	
• Equipment	Investments in machinery and equipment Investments in vehicles Investments in furniture Investments in tools and fixtures	30.000
Current assets	Investments whose effect is expected in the period <1 year	
• Supplies	Investments in raw materials Investments in goods Investments in spare parts	
•Prepaid expenses	Costs that must occur before the start of generating revenue	
• Cash Money	The necessary funds in the account / cash register	
Total Cost:		**31.500**

Key activities

The innovative company has provided that the production capacities of the key partners (subcontractors) are not a bottleneck. They have established such a work system to plan in advance the production and to order in advance the amount of equipment necessary to be delivered to the market. The costs of the device production are covered by customer's advanced partial payment.

The device for dismantling and installation of mechanical and electrical assemblies must be of high quality and made according to all requirements of technical documentation, which is the responsibility of producers of device components – the key partners. This satisfies the placement of the device on the market and customer requirements. The current device customers are very satisfied with the new device and the possibilities that the device allows in overhauling assemblies. The sales promotion and marketing of the innovative device were very successful in direct relations and on the Internet (Zagorac-Knežević, 2016). The higher sales performance was achieved in direct relations with customers. The whole team was maximally engaged while the negotiations with end customers were done by the team manager. In the previous work, the innovative

company has had no complaints for the new device and the repair service.

Key partners

The key partners for the production of the device for dismantling and installation of not-easily detachable mechanical and electrical assemblies are the producers of the device components. Machine components of the device for dismantling and assembling are produced by the companies engaged in the manufacture of mechanical component and device parts, on the basis of the device technical documentation. In this process, tolerances or accuracy of parts are very important as well as their chemical-thermal treatment. Jeep – Commerce, Belgrade, supplies the material; parts are machined in Alatnica-Lazarević, Belgrade; and chemical-thermal treatment of mechanical elements is carried out by Nitro Jon, Stara Pazova.

The hydraulic part and the heating unit are purchased on the market from known and reputable manufacturers who supply them with the product quality assurance reports and certifications. The hydraulic part is delivered by Sloga, Nova Varoš, and other companies such as Lincoss from Hungary or Einhell and Womax from Germany. The heating unit is supplied byTeleoptik, Zemun. In this way, the innovative company provides high quality of its product. The key partners are very responsible so that there are no delays in deliveries to customers.

Cost structure

In the production of the device, significant funding goes for: materials, mechanical and chemical-thermal treatment of mechanical components of the unit, the hydraulic unit and the heating unit. In addition, there are also fixed costs in the company business. The cost of communications with customers is not particularly pronounced (Zagorac-Knežević, 2016). The variable and fixed costs are provided in Table 5.

Table 5 – Variable and fixed costs
Таблица 5 – Вариабельные и фиксированные расходы
Табела 5 – Варијабилни и фиксни трошкови

VARIABLE OPERATING COSTS		A	B
		(Currency) €	(Currency) €
		The selling price set device	Price of services per one engagement
1.	The selling price of the product / service	**6.000**	**12.000**
2.	**VARIABLE COSTS (per unit of product)**		
2.1	Cost of raw materials / materials	**1.800**	
2.2	Costs of distribution and sales	**200**	
2.3	The costs of packaging	**100**	
2.4	Energy costs	**100**	
2.5	Variable operating costs	**650**	**1.000**
2.6	Costs of communication with customers	**150**	
3.	**TOTAL VARIABLE COSTS PER UNIT OF PRODUCT / SERVICE**	**3.000**	**1.000**
4.	**TOTAL PRICE OF-VARIABLE Per-unit cost (1.-2.)**	**3.000**	**11.000**

FIXED MONTHLY OPERATING COSTS	Currency €	Comments
Fixed salaries of the employees	2.400	3 employees within the team
• Electricity	100	
• Depreciation	350	
Other fixed costs:		
• Accounting services	50	
• Telephone / internet	100	
• Maintenance / Cleaning	100	
• Other		
TOTAL FIXED COSTS	3.100	

Contribution coverage = The selling price of the unit-Variable unit costs

Contribution coverage = 6.000 € – 3.000 € = 3.000 €

Breakeven point = Fixed costs / contribution to cover

Breakeven point = 3.100 / 3.000 = 1.033 €

The breakeven point is reached by selling two sets of equipment for dismantling and assembly.

Part III - The value of the company

Pitch to investors

The innovative company performs overhauls of plants in the field, using its new device simply, with good quality and without damaging parts. This team is very professional. It has been selling the device for 4 years, with a plan to sell 300 sets of equipment over the next 5 years (Rašković-Depalov, 2016).

Expansion Potential - Scalability

The new device has broad application possibilities. The innovative company is sure that it can be successful in the market for the next 10 years. The device is not easy to copy or reproduce. It takes a lot of knowledge in the field of materials and many years of experience in the technical maintenance of systems. In the first year of production, the business model requirements regarding research, development, certification and implementation of the new device were met. The breakeven point was realized with the sale of the first 2 device sets. In the first year, 5 sets were sold, which means that certain financial profit was made. In addition, overhaul services largely contributed to the increase in profits. This shows that the project is highly profitable. It has been successful on the market for 4 years. The device has various possibilities of application and may satisfy an increase in requests and the large number of customers, without changing the application itself. The aim is to achieve linearity in the speed of response to requests from customers (Petrov, 2016a), (Petrov, 2016b).

The parameters for determining the value of the company

For the first 12 months, the innovative company is planning to sell 30 sets of equipment. The unit price is 6.000 €. The variable costs per 1 unit amount to € 3,000. The fixed cost is 3.100 €. One repair service is planned at a price of 12.000 €. Variable costs amount to 1,000 € (travel expenses, accommodation and daily allowance). The planned earnings are 54.230 Euros. The income statement is presented in Table 6.

Table 6 – Balance sheet
Таблица 6 – Баланс
Табела 6 – Биланс успеха

INCOME STATEMENT FOR THE FIRST 12 MONTHS OF OPERATIONS (after completion of development)			
BUSINESS INCOME	**Currency €**	**OPERATING COSTS €**	**Currency €**
Revenues from sales		**1. VARIABLE COSTS**	
A -1 Device set	180.000	90.000	90.000
B- 1 service of theplant overhaul	12.000	1.000	1.000
		2. FIXED COSTS	37.200
Other income			
TOTAL OPERATING INCOME	**192.000**	**TOTAL OPERATING COSTS**	**128.200**
OPERATING PROFIT / LOSS			
FINANCE INCOME		FINANCIAL EXPENSES	
Interest income		Interest expense	
Other finance income		Other financial expenses	
FINANCIAL PROFIT / LOSS			
PROFIT / LOSS BEFORE TAXATION			**63.800**
INCOME TAX (15%)			9.570
PROFIT / LOSS FOR THE PERIOD OF 12 MONTHS			**54.230**

In the previous period (Year 0), the innovative company sold 20 sets of equipment at a price of 6,000 Euros each. One overhaul service was performed. The cash outflow for variable costs was in the amount of

64,000 Euros, which amounts to 168,000 Euros. The fixed costs were 12,400 Euros. The profit was 91,600 Euros. In the current year (Year 1), there is a plan to sell 30 device sets and to perform one overhaul service. The plan is to purchase a service vehicle and equipment in the amount of 30,000 Euros. The planned total earnings are 28,430 Euros.

The cash flows for the previous year and the current year operations are given in Table 7.

Table 7 – Cash Flow
Таблица 7 – Потоки денежных средств
Табела 7 – Новчани токови

ESTIMATED CASH FLOWS		
	Years	Years
	0	**1**
Cash flow from operating activities		
1. Cash inflow from products and services	168.000	192.000
2. Other cash inflow		
3. Outflows from variable costs	64.000	91.000
4. Outflows of fixed costs (excluding depreciation	12.400	33.000
5. Other outflows		
I Net cash flow from operating activities (1st + 2nd-3rd-4th-5th).	***91.600***	**68.000**
Cash flow from investing activities		
1. Sale of property, plant and equipment		
2. Purchase of property, plant and equipment		30.000
II Cash flows from investing activities (1.-2.)		**-30.000**
Cash flow from financing activities		
1. Capital Increase		
2. The resulting credits		
3. Donations, subsidies, grants		
4. Loan repayment		
5. Income tax		9.570
III Net cash flow from financing activities (1st + 2nd + 3rd-4th-5th).		**-9.570**
IV Net cash inflow / outflow period (I + II + III)		**28.430**
V- In Cash at the beginning of the period	91.600	91.600
Cash at the end of the period (IV + V)		120.030

Appendix: Documentation on services of performed overhaul

Appendix 1 Installation of the geared motor in MHE- Podgor-Montenegro

ZAPISNIK O ISPORUCI I IZVRŠENIM RADOVIMA MONTAŽE ZUPČASTOG REDUKTORA TIP FLENDER WGW SAN 280/SO- NEMAČKA, FAB. BR. 88212-0-1078/22410 u MHE PODGOR

Na osnovu Ugovora br.3541 od 18.10.2013 između Elektroprivrede Crne Gore (naručilac radova) i firme (isporučilac i izvršilac radova), izvršena je nabavka i isporuka zupčastog reduktora tip Flender WGW SAN 280/SO-Nremačka, fab.br. 88212-0-1078/22410.

Isproručilac reduktora imao je obavezu da montira zupčasti reduktor u MHE Podgor.

Dana 10.04.2014. stručna lica iz firme 0c, izvršila su demontažu neispravnog reduktora u hidroelektrani Podgor. Izvršene su sve pripreme i radovi radi montaže novog reduktora. Proizvođač reduktora sipao je originalno ulje u reduktor Total Carter EP 220. Na novi reduktor ugrađeni su ispravni delovi na pogonskom vratilu reduktora glavčina Flender spojnice tip N-EUPEX veličine A 480 i na gonjenom vratilu reduktora prirubnica Flender- lamelaste spojnice tip Arpex, veličina 270, serija K 430.

Izvršena je zamena elastičnih gumenih umetaka (10 komada) u spojnici tip Flender N-Eupex A 480.

Izvršena je nivelacija i centracija novog zupčastog reduktora na temelju, a nakon toga izvršena je provera da li je reduktor čvrsto vezan za temelj s obzirom da nisu dozvoljena pomeranja sklopa u toku rada.

Prema tehničkoj dokumentaciji za montažu reduktora i flenderovih spojnica, izvršena je provera razmaka prirubnica na Flender spojnici tip Arpex veličina 270. Propisano je da se taj razmak meri na 6 mernih mesta i da se nalazi u granicama od $S1_{min}$=22.5 mm do $S1_{max}$=23.5.mm. Izmerene vrednosti nalazile su se u tim granicama.

Propisane vrednosti razmaka između glavčina spojnice tip Flender moraju se nalaziti u granicama S= 5 do 10 mm, što je zadovoljeno kod montaže novog reduktora. U toku montaže novog reduktora zadovoljeni su svi uslovi koji su propisani po tehničkoj dokumentaciji kao što su momenti pritezanja zavrtnjeva (vijaka), spajanje ostalih delova instalacije na reduktor-cevi za hlađenje reduktora, merni instrumenti i ostalo.

Nakon izvršene montaže reduktora, mini hidroelektrana je puštena u probni rad i izvršena su testiranja rada na različitim režimima rada i opterećenjima elektrane. Utvrđeno je, da elektrana ispravno radi. Radne temperature ulja u reduktoru nalaze se u propisanim granicama. Reduktor mirno radi bez povišenih vibracija i buke.

Nakon svih aktivnosti MHE Podgor puštena je u opreativni rad u sistemu Elektroprivrede Crne Gore.

Naručilac radova nema primedbi na isporučeni sklop, rezervne delove i izvršene radove. Preuzeo je obavezu da će se pridržavati svih normi u garantnom roku.

ZA MHE PODGOR

U Podgoru, 10.04.2014.

Zapisnik dostavljen:
-HE Perućica,
-Službi MHE,

Appendix 2 - Minutes on the repair of damage to the assemblies of the MHE Montenegro

ZAPISNIK O SANACIJI GREJANJA LEŽAJA U MINIHIDROELEKTRANI PODGOR

Na osnovu Poziva br. 57/06 na otvoreni postupak javne nabavke od 26.10.2013. za rešavanje problema grejanja ležaja u MHE "PODGOR" u periodu od 11.12. do 13.12.2013. izvršeni su sledeći radovi:

1. Demontaža elastičnih spojnica tipa *Flender ARPEX K 430-Veličina 270*, koje povezuju multiplikator i generator MHE,
2. Demontaža prirubnica sa osovine zamajca postrojenja,
3. Demontaža kotrljajnih ležajeva tipa *SKF 22220 HLK+H 320* sa osovine zamajca,
4. Vizuelni pregled demontiranih delova, osovine zamajca, elemenata elastične spojnice, kotrljajnih ležajeva, kućišta i postolja ležajeva zamajca,
5. Utvrđivanje uzroka pregrejavanja kotrljajnih ležajeva zamajca,
6. Merenje rukavaca osovine zamajca,
7. Izrada alata za propisnu montažu čaura (hilzni) kotrljajnih ležajeva zamajca,
8. Montaža novih kotrljajnih ležajeva sa pripadajućim hilznama *22220 EK+H 320*. Delove je obezbedio naručioc posla u skladu sa zahtevima tehničke dokumentacije,
9. Montaža prirubnica na osovnu zamajca,
10. Montaža elastičnih spojnica tipa *Flender-Arpex K 430 veličina 270,* između zamajca i reduktora odnosno zamajca i generatora MHE,
11. Centriranje zamajca u odnosu na multiplikator i generator MHE.
12. Puštanje MHE u probni rad.
13. Merenje vibracija (prema planu merenja) u tri međusobno okomita smera: vertikalni smer, bočni smer i uzdužni smer. Merenje vibracija izvršeno je na određenim mernim mestima na: turbini, multiplikatoru, ležajevima zamajca i ležajevima generatora.
14. Izvršena je laserska provera centričnosti sklopova MHE. Na osnovu izmerenih nivoa vibracija nije bilo potrebe za dinamičkim uravnotežavanjem sistema.
    Radove pod tč. 13. i 14. izvodila je firma a sve ostale radove firma (kao što je naznaceno u datoj ponudi za sanaciju grejanja ležaja). Izveštaji o merenju dostavljeni su naručiocu posla, firmama (uručeni g. i (izveštaj će dostaviti firma).
15. Nakon izvšenog testiranja konstatovano je da se MHE-Podgor može pustiti u operativni rad.
16. Puštanje u operativni rad MHE-Podgor u sistem EPCG.

Mast za podmazivanje ležajeva tipa *Shell Alvania RL -3* obezbezbedio je izvođač radova.
Naručioc posla obezbedio je odgovarajuće rezervne delove i uslove rada: stručno lice za rad u elektrani-puštanje u pogon elektrane, rukovanje sa razvodnim ormarima, električnim uređajima, ispravnu kransku dizalicu i sajle za podizanje zamajca. Garancija na izvedene radove je 30 dana. Garancija se daje za kvalitetu usluge. Naručioc posla odgovoran je za kvalitet rezervnih delova.
Naručioc posla ima obavezu da u roku od 7 dana izvrši uplatu za izvršene usluge u celosti (pošto nije uplaćen avans) za izvođenje radova firmi koju je angažovala firma prema naznačenim partijama radova u tenderu.

ZA MHE-PODGOR

U Podgoru-Crna Gora, 13.12.2013.

Zapisnik dostavljen:
-HE-Perućica-MHE-Podgor,
-
-
-

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Conclusion

The paper presents the experience in the development of an innovation in terms of its scientific verification and its placement on the market. The techno-economic analysis of the new device was carried out.

An example of developing a business model based on the innovative product is given.

The new device for dismantling and assembling the parts of not-easily detachable assemblies on mechanical and electrical installations has enabled the company to develop an innovative new technology of on-site overhaul, new ways of organizing work and the execution of light and intermediate level repair, general revision and overhaul in field conditions. In addition to the placement of the device on the market, the innovative company carries out planned system maintenance and specialized measurements: measurement and analysis of vibrations - vibrodiagnostic assessment of the technical condition of the system, the laser alignment of assemblies, thermal imaging, developing various types of software, delivery and installation of modern monitoring systems, and others. The construction of the new device combines two basic functions: dismantling and assembly of assemblies. The device is modular and consists of 3 parts: the mechanical part (mechanical components of the device), the hydraulic part and the unit for heating parts that are dismantled or assembled.

It is easy to use, there is no possibility of damage to parts during operation and it is easy to carry. The unit weighs 25 kg. This universal device enables overhauling assemblies of different manufacturers in the field conditions. It has a wide range of applications, which until now was not the case.

The universality of the device application is achieved through various combinations of the constituent parts of the device - it does not mean that the number of component parts increases, but that individual components are constructed and adapted to cover different sizes and dimensions of various assemblies to be overhauled.

The device is intended for the external dimensions of assemblies in the range of ∅ 100-1000 mm, external shaft diameter ∅ from 50 to 300 mm, for extremely large overlaps in the firm shaft - aperture fitting to 0.02 mm The length of fitting can reach up to 300 mm. The dimensions smaller than the above measures do not represent a problem for dismantling and assembly since they can be done with bearing pullers and spatial tools and kits.

The assembly weight is not a problem for the implementation of the new device, because assemblies are pulled up, moved, and pulled down back to their original position by means of various cranes in aggregate rooms where overhaul is carried out.

In addition to the new device delivered, end customers are provided with technical maintenance service, delivery of spare parts and training of technical personnel.

The new device reduces the cost of plant maintenance up to 50% compared to earlier overhaul technologies, when assemblies were transported to specialized workshops and overhaul institutes. The time required to perform overhaul is significantly reduced. For example, if the intermediate-level repair of a mini hydro power plant of 500 KW used to take 30 days, now overhauling can be executed in 15 days with the overhaul costs halved.

In the period from 2002 to 2016, in the system of the Electrical industry Montenegro, higher overhaul levels in 18 mini hydroelectric power plants were carried out according to the plans. On some systems, overhauls were carried out several times, since the hydro power plants are in continuous operation, because of the huge influx of water in the operation season and opportunities for major electric power generation. This enables the customer to realize substantial profits, with minimal maintenance costs. In addition, the customer has gained significant financial resources for the purchase of new energy systems to replace the existing old systems or for the purchase and installation of systems on new locations.

The innovative company enabled similar gains to other customers as well.

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ОПЫТ В РАЗВИТИИ ИННОВАЦИЙ С ТОЧКИ ЗРЕНИЯ НАУЧНОЙ ВЕРИФИКАЦИИ И ПРОДВИЖЕНИЯ ГОТОВОЙ ПРОДУКЦИИ НА РЫНКЕ

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ВИД СТАТЬИ: оригинальная научная статья
ЯЗЫК СТАТЬИ: английский

Резюме:

В данной статье описано инновационное монтажно-демонтажное устройство сложно разбираемых узлов машиностроительного и электротехнического оборудования, разработанное для условий полевого ремонта. Новизна состоит в том, что с помощью данного устройства намного ускорен процесс сборно-разборочных работ, а возможность повреждений практически исключена. Это переносное устройство, которое отличается легкостью в использовании. Оно применяется на всех этапах полевого ремонта любых видов станций и сооружений.

Данное устройство присутствует на рынке сбыта уже 4 года. Предполагаемые сроки его эксплуатации составляют 10 и более лет. При разработке данного монтажно-демонтажного устройства для машиностроительных и электротехнических узлов, были учтены все выявленные за время многолетнего опыта в области содержания и ремонта станций и сооружений

проблемы, в частности невозможность выполнения разборочно-сборочных работ в условиях полевого ремонта.

Инновационное устройство обеспечило возможность развития новой технологии ремонта станций и сооружений, внедрены новые методы организации и выполнения ремонтных работ. Благодаря большому опыту и знаниям команды разработчиков, для осуществления идеи не понадобилось много времени (потребовалось всего 6 месяцев для осуществления целого проекта).

Продажа настоящего устройства производится в конфиденциальном порядке, оговоренном договорными обязательствами, которые подразумевают неразглашение информации о конструкции, а также инструкции по эксплуатации устройства. В настоящий момент в Институте интеллектуальной собственности города Белград оформляется защита интеллектуальной собственности данного устройства, и по его завершении планируется подача международной заявки на патент (защита PCT).

Ключевые слова: инновация, новое устройство, монтажно-демонтажные работы, сложно разбираемые узлы, ремонт, машиностроительные и электротехнические сооружения, мини-ГЭС, судостроение, военная промышленность, бизнес-модель, компания по инновационным проектам, технико-экономическое обоснование.

ИСКУСТВА У РАЗВОЈУ ИНОВАЦИЈЕ СА АСПЕКТА НАУЧНЕ ВЕРИФИКАЦИЈЕ И ПЛАСМАНА ГОТОВОГ ПРОИЗВОДА НА ТРЖИШТЕ

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Сажетак:

Иновативни уређај за демонатжу и монтажу делова тешко растављивих склопова на машинским и електропостројењима у теренским условима ремонта омогућава брзу и ефикасану демонтажу и монтажу делова, без могућности оштећења. Једноставан је за употребу и лако се преноси. Може се примени-

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ти за све врсте постројења и више нивое ремонта у теренским условима рада.

Уређај се налази на тржишту четири године, а очекује се да ће се користити наредних 10 година, а вероватно и дуже. Током дугогодишњег рада на пословима одржавања постројења било је много проблема у ремонту, па је развијен уређај за демонтажу и монтажу машинских и електросклопова. Многи склопови нису могли бити демонтирани и монтирани у теренским условима рада. Нови уређај омогућио је да се развије нова технологија ремонта постројења на местима где су инсталирана, затим нови начини рада у организацији и извршењу ремонта. Од идеје до реализације уређаја прошло је само 6 месеци, пошто тим има велико искуство на овим и сличним пословима. Иновативни уређај купцима се испоручује уз уговорне обавезе о продаји уређаја и ремонту система, а дефинише се и заштита тајности конструкције и примене уређаја.

У току је поступак заштите уређаја код Завода за интелектуалну својину у Београду, а након тога биће поднета и међународна пријава за патентну заштиту (заштита PCT).

Кључне речи: иновација, нови уређај, демонтажа и монтажа, тешко растављиви склопови, ремонт, машинска и електропостројења, мини- хидролектране, бродоградња, војна индустрија, пословни модел, иновативна компанија, техно-економска анализа.

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MATHEMATICAL MODELING AND IDENTIFICATION OF THE MATHEMATICAL MODEL PARAMETERS OF DIESEL FUEL INJECTION SYSTEMS

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Abstract:

The aim of the paper is to highlight, if not all, then at least the most important benefits of the application of mathematical modeling in the development of a new solution or in the process of improvement and the optimization of an existing product. The thesis presents the basic principles of the model creation without providing a detailed mathematical interpretation of the process; therefore, the model includes a substantial number of unknown or approximately known parameters and it is not possible to create a model of the transparent cybernetic box type. In order to achieve a synthesis of the model and the experimental results, it is necessary to apply the optimization methods for the identification of unknown model parameters. The thesis presents the experimental results along with the results of modeling and identification as well as the analysis of the process of identification of unknown model parameters.

Key words: diesel engine, fuel injection system, mathematical modeling, identification.

Introduction

Te fuel injection system for diesel engines is a mechanical-hydraulic system in which the processes happen very fast and in which very high fuel pressure develops - with motors of the latest generation even over 2,000 bar.

The fuel injection process itself lasts for less than 2 milliseconds and it can be compared only with the duration of a gunshot. If we add to it the fact that the system should ensure the repeatability of the process during the working life of the engine of 5,000 and even 10,000 hours, with about 1,000 cycles per each cylinder (i.e. 4,000 cycles for the entire motor) during each minute in a high-speed four-cylinder four-stroke diesel engine, it becomes clear how much inventiveness and knowledge is necessary for the design and creation of such a system.

In order to critically analyze and evaluate various impacts, the structural, functional, as well as various external disturbances, a good knowledge of the physics of the processes within the system is necessary. The conditions for defining the relations between the input and output parameters and the impacts of the disruption on the operation of the system are thus created. There are two methods available – the empirical one and the theoretical one.

The first method provides reliable information in terms of perceiving the integral, macro characteristics of the process, since the experimental methods do not allow access to all physical values of the process. Evaluation of the physical quantities that cannot be determined experimentally requires the introduction of assumptions, which raises a question of reliability of conclusions obtained in such a way. It is even possible to make wrong judgments. And when it comes to the experimental method, if we take into consideration the subjective characteristics of researchers such as experience, intuition and talent, the process of identifying the most optimal solution from the set of possible solutions is expensive and time-consuming.

Another procedure, analytical one, implies the creation of an idealized mathematical model for the simulation of the mechanical and hydrodynamic processes in the system. If the mathematical model fully imitated the real system, preconditions would be created for the analysis of the process both on the macro and the micro level and in the aspects that are unreachable by experimental methods.

Experience shows that, due to the complexity of the process in the system, it is most rational to combine both methods.

In the following section, an example will be presented of mathematical modeling of the pump - pipe – injector system, with an emphasis on the process of identification of unknown model parameters by applying the optimization methods. This system, in different varieties, has been long in use with diesel engines and there are a large number of publications devoted to the mathematical interpretation of the process within the system and the methods of model solving. The process proposed here has been im-

plemented for practical purposes, applied in several Research & Development projects, and the results have been implemented in materialized systems.

The whole "package" also includes the process of the system optimization; however, it will not be discussed here due to the limited space.

Mathematical modeling of the process

There is a certain disagreement about the definition of the model and the role of the modeling of physical processes and systems. Therefore, due toits comprehensiveness, the often quoted definition of M. Pešelis given here: "The term ‘model’ is used in the broadest sense as a structure for storing knowledge, in which the leading role is played by the idea of reduction of information. The reduction of information is in the closest possible way related to the establishment of relations between different groups of information, and therefore to the issues of acquainting with the structure and function of the system. Therefore, the development of the models represents an important aid to obtain new information on the basis of already existing special knowledge" (Jankov, 1984, p.20).

The end result of the development and implementation of the mathematical model is to obtain reliable information on the basis of which researchers will be able to choose the best solution in the given circumstances, having in mind certain limitations. The very procedure of the construction and application of the model consists of several steps:

1. The formulation of the problem.
2. The collection of the data on the system and the identification of external influences in case the system interacts with other systems.
3. The development of a mathematical model using mathematical methods.
4. The analysis of the impact of certain (according to researchers – important) parameters of the model parameters on the system processes.
5. The identification of unknown model parameters, in case the model is in the form of a cybernetic semi-transparent box.
6. The optimization of the system – application of the optimization method on the identified model.
7. The evaluation of the obtained results, in which available experimental results are of particular importance as well as the experience and knowledge of researchers. The role of researchers is indispensable because the model cannot provide all the answers.

8. The last phase is the implementation of the results into the process of designing a new or modifying the existing solution.

When creating a mathematical model of a complex system, it may happen that the mathematical interpretation of physical processes is superfluously cumbersome or that certain processes cannot be described analytically. In this case, simplifications must be introduced under certain assumptions which should be taken into account when making decisions at the stage of evaluation and implementation of results. On the other hand, the model provides information complex to the extent of how complexly the physical process is mathematically described.

It has already been pointed out that there are a number of published papers devoted to the problems of mathematical modeling of fuel injection systems, and it is up to researchers to apply the already developed model with or without alterations or by respecting the physical laws to build their own solution. Therefore, the thesis will expose only the basic principles common to all the models analyzed by the author, without introducing details.

In line with the form, the system can be divided into components. Their number depends on the configuration of the system. The elementary system consists of the piston mechanism, a working space in the pump's cylinder, a delivery valve, a pipe, a chamber in the injector and the injector needle with all the moving parts. Control (regulatory) elements on the pump or the nozzle can also be found. Fuel is a separate component, the physical characteristics of which, in real conditions and according to the experience of the author based on experimental results, deviate significantly from the values obtained in stationary conditions.

In the mathematical model used, a separate software module is formed for each component and mutual influences are defined. There are a number of reasons for dividing the system into components, and only two will be mentioned. First, it is easier to monitor and understand the semantics, i.e. the contents and the meaning of the model, as well as the limitations and conditions for the similarity of the modeling results and the characteristics of the real system. Secondly, it allows an easy application of the model to other systems of various forms by replacing the existing modules or adding new ones.

Further on, only the basics of the creation of the mathematical interpretation of physical processes in the system will be displayed. Displaying all the details of only one of possible options requires significantly more space.

The first assumption - the system can be extracted from the engine, i.e. a higher-level system, and considered separately while defining and respecting the impact of the engine, but also that of the environment.

For all the chambers in certain parts of the system, the expressions for determining pressure and other fuel physical properties are obtained from mass balance expressed though mass flows, which, assuming that fuel is compressible, homogeneous and isentropic and that pressure is equal in the whole area when mass is equal to the result of multiplying the density and volume $m = \rho V$, reads as follows:

$$\frac{dm}{dt} = V\frac{d\rho}{dt} + \rho\frac{dV}{dt} = \frac{dm_u}{dt} - \frac{dm_i}{dt} - \frac{dm_g}{dt} \tag{1}$$

And from the equation of state in the form:

$p = p(\rho, s)$ if it is assumed that the process is isentropic,

$p = p(\rho, T)$ if it is assumed that the process is isothermal.

Where $dm_u / dt - dm_i / dt$ is the balance of the mass flow through the inlet and outlet orifices for communication of the control space with the adjacent parts of the system, and dm_g / dt represents undesired fuel loss from the monitored space. Losses occur with fuel flowing through technological gaps in the pump and the injector. It should be emphasized that the fuel density and the control volume value are not constant. Density depends on pressure, temperature and the concentration of the gaseous phase, the presence of which, according to empirical data, cannot be ignored. Volume is variable for most of the mentioned spaces and depends on the current position of the system moving parts. The change in volume caused by the elastic deformation of the parts is practically negligible.

If we define the fuel compressibility via the so-called compressibility coefficient $\alpha = -\frac{\left(\frac{\partial V}{\partial p}\right)}{V}$, the expression for determining the pressure in one of the system chambers will be formed as:

$$\frac{dp}{dt} = \frac{1}{V \cdot \alpha} \cdot \left[\sum Q_i + \sum A_j \cdot v_j\right] \tag{2}$$

where the first Sum in the parentheses is the balance of the fuel flow at the boundaries of the control space with the volume V, and the second Sum is the balance of the shifts of space boundaries (the piston, the valve, etc.).

It should be particularly emphasized that the engine, directly linked to the analyzed system, is a cyclic machine by the nature of the work process. In the time period that includes a multiple number of cycles, it is an imperative to have the repeatability of the cycle. This means the repeatability of the angular velocity from cycle to cycle, i.e. the equality of the mean angular velocity of the engine crankshaft, i.e. the angular velocity of the pump's camshaft of the observed system from cycle to cycle. During one working cycle, angular speed is variable; therefore, in order to understand the process, it is more convenient to regard the fuel injection system as a function of the camshaft position (as a reference shaft), and not as a function of time. This is achieved by introducing the following expression:

$$\frac{\partial p}{\partial t} = \frac{\partial p}{\partial \varphi} \cdot \frac{\partial \varphi}{\partial t} = \frac{\partial p}{\partial \varphi} \cdot \omega \tag{3}$$

where φ is the angular position of the reference shaft in relation to a certain reference position, and ω is a current value of the angular velocity of the shaft in the position φ.

The modeling of the fluid flow through the inlet and outlet orifices, generally irregular in shape, would significantly burden the model. Practice shows that, with sufficient accuracy, Bernoulli's expression for the flow ratecan be used with the introduction of a correction, the flow coefficient μ of a constant value, with which the theoretically idealized results approach the real process. Thus, the volume flow Qthrough the geometric flow cross section Acan be determined from the following expression, with a difference in pressure Δp:

$$Q = \mu \cdot A \cdot \Delta p \cdot \sqrt{\frac{2}{\rho \cdot |\Delta p|}} \tag{4}$$

The form of a gap between the cylindrical surfaces through which losses occur is unknown because the straightness and roundness of the parts' surfaces are of the same order as the nominal gap. Neither is known any eccentricity of the parts, so it is practically impossible to make a mathematical model to calculate the loss of working fluid. In literature, there are a lot of semi-empirical expressions, out of which, based on the experimental results, the expressions of Astakhov (Astakhov, 1972) simulate the real process the best.

The position, i.e. the movement of freely moving parts of the system of mass m (the valve, the absorber, the injector needle, etc.) is determined from the equality of inertial forces and forces F_i which act on the movable part:

$$m \cdot \frac{d^2x}{dt^2} = \sum_{i=1}^{n} F_i \tag{5}$$

Friction forces as a constant value and damping forces linearly dependent on the movement speed should also be included into the sum of the forces. Also, from the standpoint of the stability of the model integration process, the following has been proven useful to include in the model: deformation of the system elements restricting the movement of the parts in the boundary positions, as well as the friction forces during the movement in the deformation zone. This eliminates the discontinuity of the calculated values and increases the stability of the integration process.

The flow in the pipe is three-dimensional and unsteady, with variable physical characteristics of the fuel. Mathematical expressions to describe such flow are very complex and unsuitable for practical use. It has turned out that, with certain simplifications, the expressions of the mass and impulse conservation law can be transformed into a form suitable for solving while preserving the process physical aspect. If we introduce the following assumptions:

- The pipecross section is constant and multiple times smaller than the length, so it can be adopted that the flow is one-dimensional and linear;
- Disturbances are transmitted at the speed of sound by waves perpendicular to the movement direction - the pipe;
- The change of the working fluidstate is isentropic and the speed of sound can be calculated from Laplace's expression

$$a^2 = \partial p / \partial \rho$$

- The fuel characteristics depend only on pressure, and
- Gravitation is negligible,

the expressions acquire a simpler form:

$$\frac{\partial \rho}{\partial t} + v \cdot \frac{\partial \rho}{\partial x} + a^2 \cdot \rho \cdot \frac{\partial v}{\partial x} = 0 \tag{6}$$

$$\frac{\partial v}{\partial t} + v \cdot \frac{\partial v}{\partial x} + \frac{1}{\rho} \cdot \frac{\partial p}{\partial x} + \frac{1}{\rho} \cdot \frac{\partial p_{sr}}{\partial x} = 0 \tag{7}$$

According to Darsy and Weisbach, the hydraulic friction force at a unit volume (the last item in the second expression) is a non-linear function of the fluid velocity, which is not convenient from the point of integration. The expression can be linearized by introducing the coefficient of hydraulic resistance *K* that linearly depends on the flow velocity; however, it is adopted that it has a constant value in a single integration step and is calculated for

each step on the basis of the mean flow velocity. Thus, the previous expressions obtain the following form:

$$\frac{\partial p}{\partial t}+v\cdot\frac{\partial p}{\partial x}+a^2\cdot\rho\cdot\frac{\partial v}{\partial x}=0 \quad and \quad \frac{\partial v}{\partial t}+v\cdot\frac{\partial v}{\partial x}+\frac{1}{\rho}\cdot\frac{\partial p}{\partial x}=2Kv \tag{8}$$

And finally, fuel is regarded as a separate component; its physical characteristics in stationary conditions depend on pressure and temperature and can be determined with the help of published empirical expressions (Huber, Schafitz, 1966). However, the experimental results obtained in real systems have significantly different values.

This is most apparent with the speed of propagation of disturbances in the system pipes, the value of which, according to experimental results, reaches a significantly lower value than the value obtained in stationary conditions. The reason for this is the presence of the gaseous phase in the fuel which is uniformly dispersed in the liquid phase in the form of tiny bubbles (Murzin, 1990). On the basis of a specific or adopted (presumed) gaseous phase concentration value, it is possible to determine the fuel characteristics as a function of pressure and temperature (Fox, 1977), (Thiemann, 1988). Finally, we can conclude that the fuel characteristics, density, compressibility and also the speed of propagation of disturbances depend on the pressure, temperature and concentration of the gaseous phase.

Solving the mathematical model

The mathematical model consists of a set of two partial nonlinear hyperbolic differential equations and a set of non-homogeneous nonlinear differential Cauchy - type equations of the first or second order, the number of which depends on the number of components. There is also a set of algebraic expressions and a set of restrictions and logical conditions that alter the system structure depending on the process phases. The first set of differential equations describes the fluid movement in the flow plane/coordinate system consisting of the pipe longitudinal axis and the time coordinate. The other set describes boundary conditions at the pipe end.

The fluid flow can be viewed as a wave phenomenon - as a flow induced by the propagation of waves of finite intensity, which at each point of the coordinate system determine the fuel condition. In this sense, the differential equations that describe the flow in the pipe are transformed intoa so-called "characteristic" form (Fomin, 1973) which determines the change in fluid pressure and speed along the characteristics – the trajectories of waves at the coordinate system.

$$\frac{dv}{dt}+\frac{1}{a\rho}\cdot\frac{dp}{dt}=-2\cdot K\cdot v \quad and \quad \frac{dv}{dt}-\frac{1}{a\rho}\cdot\frac{dp}{dt}=-2\cdot K\cdot v \tag{9}$$

They are solved using the so-called method of characteristics, but in order to apply numerical methods in the expressions, finite differences should be used instead of differentials. Consequently, the coordinate system should be subdivided by the rectangular network Δx– Δt, where Δx is a step along the pipe, and Δta step along the timeline axis, provided that the characteristic does not cross over from one field to another, i.e. that the requirement $\Delta x<\left(a+v\right)_{max}\cdot\Delta t$ is met, by which the numerical integration algorithmis significantly simplified. At each intersection of the net, "S+" and "S-" characteristics should be set; they are defined by differential expressions

$$dx/dt=v+a \quad \text{and} \quad dx/dt=v-a \tag{10}$$

or by the finite differences in the expressions

$$\Delta x/\Delta t=\left(v+a\right)_{sr} \text{ and } \Delta x/\Delta t=\left(v-a\right)_{sr} \tag{11}$$

in which the right members of the equations represent the average value of the sum, i.e. the differences of flow velocity and the wave propagation speed within one integration step Δt. Along the characteristics, the changes in pressure and flow velocity are calculated, thus determining their values at all nodes at the "level" $t=\left(j+1\right)\cdot\Delta t$, based on the already calculated values in all the nodes along the pipe for the "level" $t=j\cdot\Delta t$. This procedure must be synchronized with the integration of the equations of the boundary conditions which determine the pressure at the beginning and at the end of the pipe.

The second method consists of calculating Riemann's invariants (Hanjalić, 1978) along the characteristics out of which the velocity and pressure in the flow field are calculated. Both methods provide the same results with approximately the same computing time.

When selecting numerical methods for solving differential equations of boundary conditions, it should be kept in mind that the model changes the structure and that the gradients of physical values of the fuel, primarily pressure and speed, have extremely high values. Experience has shown that, due to the integration process stability, it is more convenient to use only the methods that do not require the calculations of higher order differentials. Such is, for example, the Euler-Cauchy's method, a so-called predictor-corrector method with a variable step and an iterative process of correction. The integration step varies depending on the calculated error as a difference between the results of two successive iterations in the same integration step. If, for a limited number of iterations (not more than fi-

ve) the error is greater than the adopted maximum value, the step should be reduced, and if it is lower than the lowest adopted limit value, the next step should be increased. The limit values are determined for each of the calculated values so as to obtain sufficient accuracy within a reasonable computing time.

What is provided by the mathematical model.

If we interpret it as a set of rules with which the set of input parameters is mapped onto a set of output parameters, then a change of one of the input data reflects onto some or all of the output data. This allows the implementation of systematic research – a systematic changing of one by one input data and determining the degree of their impact on the process in the system, by comparison and qualitative and quantitative evaluation of representative, output parameters. The scope of input parameters changes is determined in accordance with the model structure, physical meaning of a value and researcher's experience.

Although the mathematical model is exposed only in its basic form, without detailed mathematical interpretations of the process, it can be concluded that it contains a variety of values that are unknown or just approximately known. The model, therefore, has a form of a semi-transparent cybernetic box with a set of unknown parameters that significantly affect the process. Also, there is a second group of parameters introduced into the model primarily to improve the stability of the numerical integration procedure. Their influence on the results is not significant. It is highly unlikely that researchers, solely based on their knowledge and experience, can determine the actual values of quantities such as friction and damping forces during the motion of freely moving parts, flow coefficients, gaseous phase concentration in the fuel, etc.. The unknown parameters may also be some constructive data that cannot be reached without the destruction of the analyzed system. A model with experimentally determined unknown parameters can be used for a systematic analysis in order to acquire knowledge about the impacts of the input parameters on the process. If experimental results from similar systems are also available, it is possible to define quite reliably a relatively narrow range of unknown parameters so that the model can be used in a design phase as well.

Mathematical modeling is an essential tool for researchers in modifying, improving and optimizing realized systems or in a design of a similar solution where the results of experimental studies of the basic system are available. Experimental results provide an opportunity to identify unknown parameters and apply the modeling results with sufficient reliability in designing a desired solution.

Identification of unknown parameters of the mathematical model

In order for a computational model to fully simulate the process in the system, it is necessary that the difference between a series of modeling results and the corresponding series of experimental results for one or more characteristic process quantities is equal to zero in an ideal case. Let us denote a series of modeling results as a function of the reference shaft position and the vector of model parameters with $V_i^m\left(\varphi_i, p_j\right)$, and a corresponding series of the experimental results of the same characteristic values of the process with $V_i^e\left(\varphi_i+\varphi_0\right)+V_0^e$, where the index *i* represents the position of values of the results in a corresponding sequence. The phase shift $\varphi_0 = cost$ is a new unknown parameter with which the measuring results are coordinated with the modeling results regarding the angular position of the reference shaft, and V_0^e is a parameter that should also be determined in the case when the absolute level of the measured value must be corrected. The difference

$$V_i^e\left(\varphi_i+\varphi_0\right)+V_0^e-V_i^m\left(\varphi_i, p_j\right)=\varepsilon_i^e-\varepsilon_i^m \tag{12}$$

is the total error as a difference between the combination of random and systematic errors in measurement and modeling errors. It cannot be equal to zero either, so the task of identifying unknown parameters comes down to a search for the minimum of this difference.

The mathematical model is complex, the number of unknown parameters is large, they are mutually independent and the task cannot be solved by deterministic methods. It remains to solve the problem with statistical methods. We should formulate the error functional in the form of a sum of the squares of differences of modeled and measured *(n)* values of the characteristic value.

$$F\left(x\right)=\sum_1^n\left(V_i^e+V_0^e-V_i^m\right)^2 \tag{13}$$

In the expression, *x* denotes a vector of unknown model parameters, and only one estimation value is included in the sum of squares, although there can be more of them. The problem comes down to searching for the error functional minimum, for which optimization methods are used. At the same time, unknown parameters cannot reach an arbitrary value, but in order to preserve the process physicality, we must define the boundaries

within which an optimal value of the parameters can be sought. Any combination of parameters within the established boundaries represents a valid solution, and a set of all permissible solutions represents valid space. The mathematical model is complex, therefore it is expected that, in a set of allowed solutions, a greater number of local functional minima are obtained, and those are obtained within the search for the minimum with different initial values of unknown parameters. The search for an absolute minimum is often cumbersome, and often not even necessary in practice, so finally, the solution that corresponds to one of the local minima of the functional is accepted.

The task would be solved by analytical methods if the model had a form that allows calculating the gradients. This is not possible in this case, so the use of numerical methods is necessary. According to the experience of other researchers, out of a whole range of developed optimization methods for determining the minimum sum of squares (Tomić, 1987), (Vengerskij, et al, 1982), the highest efficiency was demonstrated by Marqurdt's method (Gill, et al, 1981) which will not be discussed further here due to space limitations.

An example of the application of the mathematical model with the identification of unknown model parameters will be shown here together with the experimental results obtained within the project of defining the fuel injection system that would be delivered by an alternative manufacturer, and that would be applied to the existing engine in a serial production as a replacement solution. The project was implemented by the Factory of Engines for Special Purposes in Pale, where the research was carried out. It should be particularly emphasized that the results presented are of a preliminary nature, they were obtained on a system that does not meet the requirements to be applied on the specific engine and they do not contain potentially confidential information for the engine manufacturer.

The experimental studies were carried outside the engine, on a test stand for the purpose of testing the system using all the elements intended to be installed in the engine. Two characteristic process quantities were measured - the fuel pressure at the pipe end and the injector needle position. The following quantities were also measured: the position of the pump camshaft, the fuel pressure and temperature and the mean value of the volumetric flow rate of fluid through the injector, i.e. the cumulative quantity for a selected number of operating cycles. The following measuring devices were used:

- Piezoelectric pressure sensor AVL 5QP,
- Sensor AVL 3056-A01,
- Needle lift inverter - hand-made inductive half bridge,

- Sensor AVL 3076-A01, and
- Encoder of camshaft angular position: optical incremental

The obtained electrical quantities are digitalized using the National Instruments data acquisition system USB 621 and stored in a personal computer.

The obtained results include systematic and random measurement errors. Out of systematic errors, two have been identified and previously discussed - the angular position of the cam profile in relation to the flow of the measured quantities and the absolute level of the measured signal of fluid pressure as a result of operating principles of piezoelectric sensors. Both errors are effectively eliminated by the procedure of identification of unknown parameters. On the other hand, random errors are of stochastic nature and they are neither possible to identify nor to eliminate. However, when random errors are subjected to normal distribution with the zero mean value, then their level becomes significantly reduced by calculating the average cycle obtained by averaging the characteristic quantity values (measured over a number of consecutive cycles, for each angular shaft position). In this case, the influence of random errors can be disregarded (Tomić, 1987).

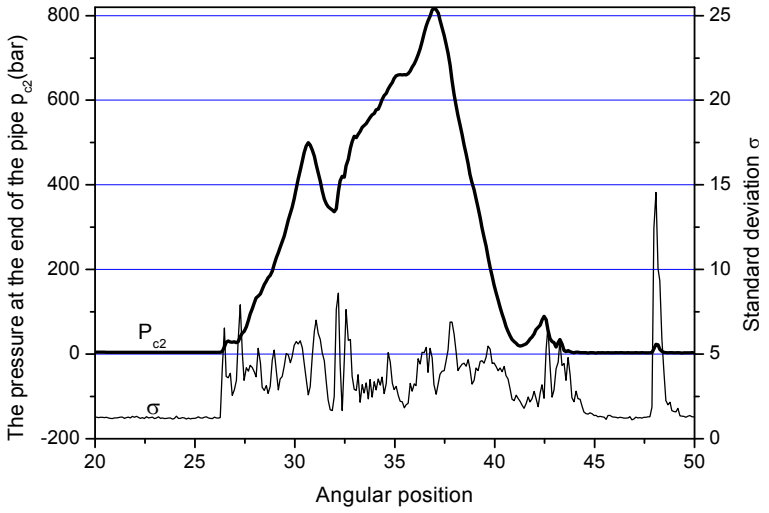

Figure 1 – The pressure at the end of the pipe and standard deviation for 50 consecutive cycles
Рис. 1 – Давление топлива на конце трубопровода для 50 последовательных циклов
Слика 1 – Притисак на крају цеви и стандардно одступање за 50 узастопних циклуса

Figs. 1 and 2 display the pressure at the pipe endaver aged for 50 consecutive cycles as well as the statistical parameters – standard deviation and Pearson's coefficients. It should be noted that the measured pressure value between two consecutive injections is equal to zero, which is a result of the fact that the measurement was performed with a piezo-electric sensor. That is why this quantity is of one of the unknown parameters that should be determined.

The value of the asymmetry coefficient is close to zero and the shape coefficient varies around a value of 3 (from 2 to 4) except in the process phases where the gradient values of the measured quantity are extremely high. This can be explained by anerror in measuring the camshaft angular position. in the process phases where the gradient of the measured quantity ishigh (up to 350bar per angle), a measuring error of one angle increment (0.1 degree) results in aconsiderable error. The value of Pearson's coefficients shows that random errors are subject to normal distribution; consequently, their impact on the measured quantity can be neglected if the values measured over a number of consecutive cycles are averaged.

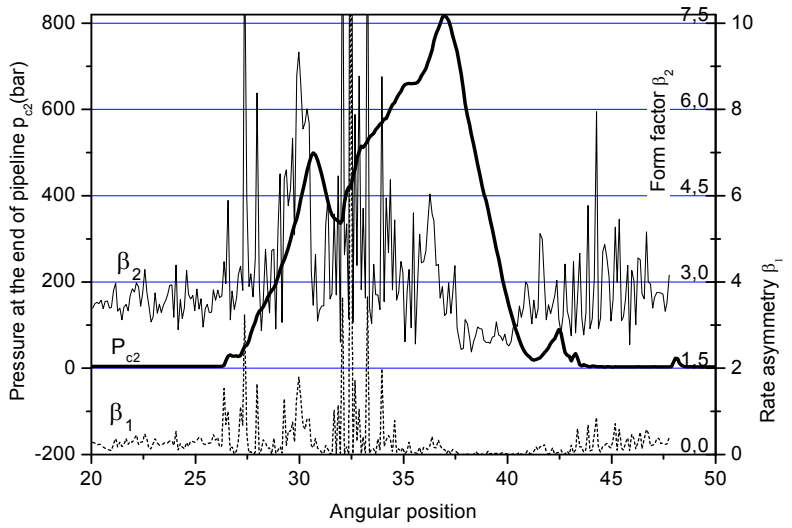

Figure 2 – The pressure at the pipe end and Pearson's coefficients for 50 consecutive cycles

Рис. 2 – Давление топлива на конце трубопровода и коеффициенты Пирсона для 50 последовательных циклов

Слика 2 – Притисак на крају цевовода и Пирсонови коефицијенти за 50 узастопних циклуса

It has already been emphasized that the identification process must be repeated multiple times with different initial values of the unknown parameters, i.e. more local minima of the functional should be found, and then one chosen as a final solution. The following illustrations display in parallel: the results of the measurements and the results of modeling with the initial and the "exact" (identified) values of the unknown parameters for two operation modes determined by the total flow through the nozzle Vc during one cycle and by the camshaft rotational speed *n*. In order to illustrate the convergence of the suggested method, in both cases a large number of parameters are identified - 10. For the same reason, the illustration shows the results of "computing" processes, with which the initial values of certain model parameters are significantly different from the "true" ones, which resulted in a large difference between the results of the identified model and the results obtained with the initial parameter values.

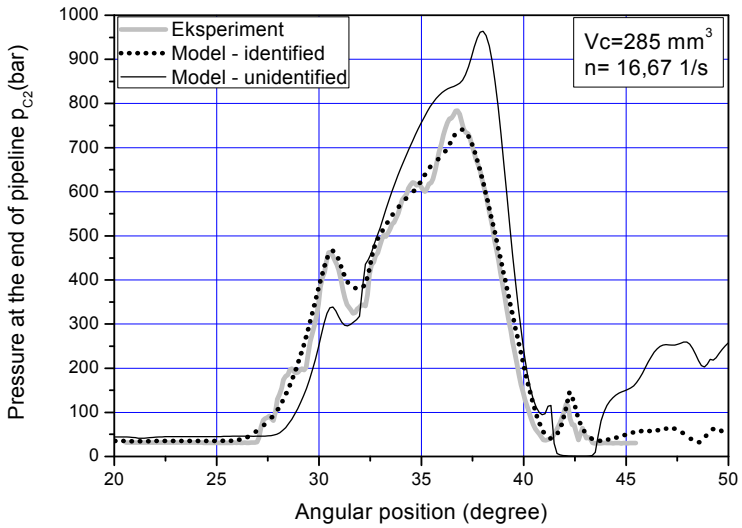

Figure 3 – Comparative review of the experimental results and the results with the initial and identified mathematical model parameters
Рис. 3 – Сравнение экспериментальных результатов и результатов моделировани с началним и идентифицированными параметрами
Слика 3 – Упоредни преглед експерименталних резултата и резултата математичког моделирања са почетним и идентификованим параметрима математичког модела

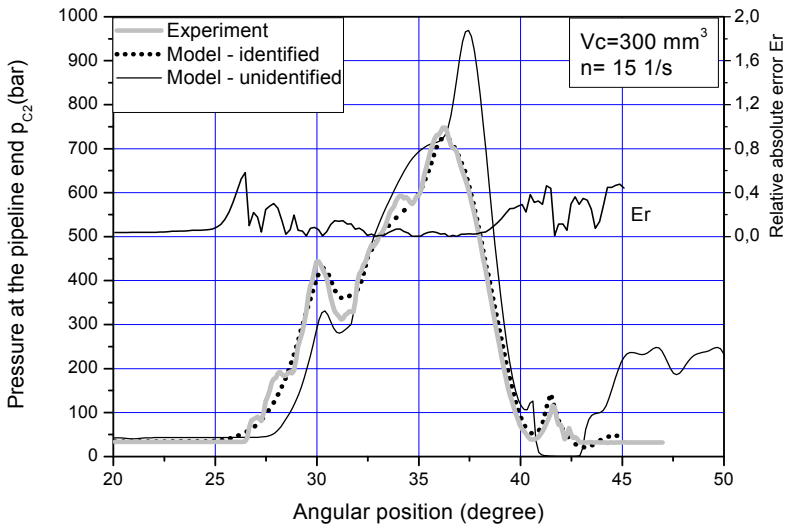

Figure 4 – Comparative review of the experimental results and the results with the initial and identified mathematical model parameters
Рис. 4 – Сравнение экспериментальных результатов и результатов моделирования с начальным и идентифицированными параметрами
Слика 4 – Упоредни преглед експерименталних резултата и резултата са почетним и идентификованим параметрима модела

The following diagrams show the course of the change of the functional and several unknown model parameters during the identification process. In the first case (Fig. 5), which corresponds to the results of Fig. 3, the allowed space in which we seek a solution is narrowed. The result is a high value of the functional and reaching the threshold values of model parameters. At first glance (Fig. 3) the results of measurements and modeling match relatively well, so a question arises whether the threshold values of other model parameters are established correctly, i.e. whether the identified model represents a real system. This example shows that, when assessing the modeling results, researchers must analyze in detail the whole process, not only the modeled and experimental values of the selected characteristic process quantities.

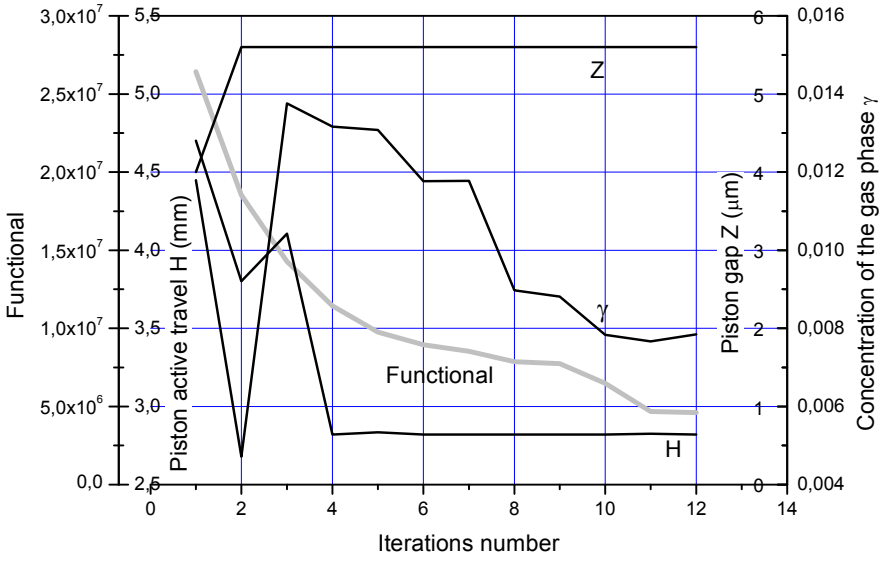

Figure 5 – The course of the process of identifying unknown model parameters
Рис. 5 – Течение процесса идентификации неизвестных параметров модели
Слика 5 – Ток поступка идентификације непознатих параметара модела

In the second example (Figs. 4 and 6), the threshold values of the parameters are determined taking into account all the known system characteristics; therefore, the final value of the functional is much lower, and the model parameters are within the permitted area.

The comparison ofthe experimental and calculated values (Fig. 4) shows that the model appropriately simulates the operational process and that the results can be used for system design and optimization. In addition, the differences observed during the change of the analyzed value indicate that the model does not fully describe the real physical process in the system, but that it can and should be improved in further research.

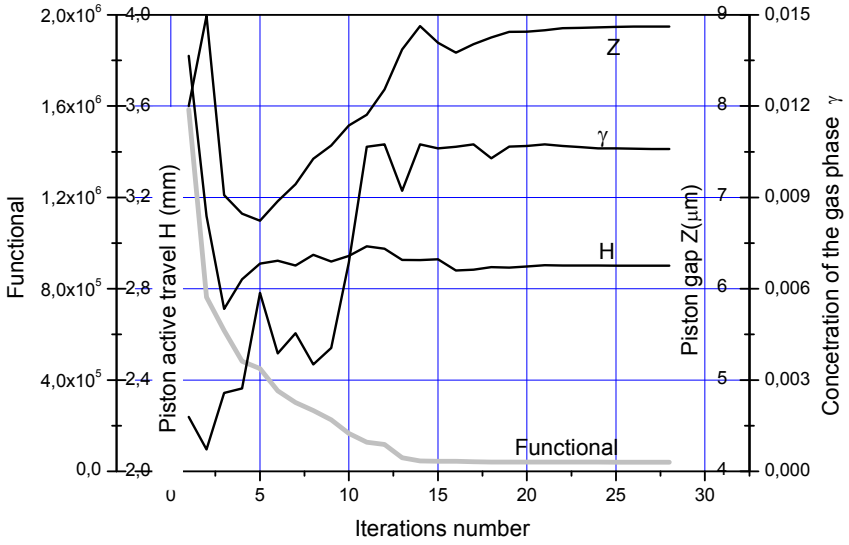

Figure 6 – The course of the process of identifying unknown model parameters
Рис. 6 – Течение процесса идентификации неизвестных параметров модели
Слика 6 – Ток поступка идентификације непознатих параметара модела

Conclusion

Mathematical modeling, with the application of optimization methods for identifying model parameters, enables connecting theoretical and empirical relations, on the one hand, with experimental results, on the other. This provides a number of benefits to researchers.

- It is possible to also gain insight into the process phases in accessible by experimental methods.
- The relationship between input and output values can be established at minimum cost - without cumbersome and detailed experimental research.
- It is possible to carry out a systematic analysis of all factors influencing the course of hydro-mechanical processes within the system and therefore to acquire relevant new knowledge.
- The mathematical interpretation of the process allows the use of optimization methods and effective identification of possible solutions leading to the choice of the best one.

Since the processes within the system are complex, a detailed mathematical interpretation leads to the creation of an unnecessarily

cumbersome model; therefore, some necessary simplifications that do not jeopardize the physicality of the process have proved to be justified in practice. This approach provides a model that appropriately simulates a real physical process. However, the model cannot be integrated by analytical methods and it is necessary to create computer programs along with the application of numerical methods.

Finally, it is possible to realize a theoretical-experimental procedure that takes the shortest route to the objective - to find the optimal solution and implement it in the development project.

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МАТЕМАТИЧЕСКОЕ МОДЕЛИРОВАНИЕ И ИДЕНТИФИКАЦИЯ ПАРАМЕТРОВ МАТЕМАТИЧЕСКОЙ МОДЕЛИ СИСТЕМЫ ВПРЫСКА ТОПЛИВА ДИЗЕЛЬНЫХ ДВИГАТЕЛЕЙ

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ВИД СТАТЬИ: оригинальная научная статья
ЯЗЫК СТАТЬИ: английский

Краткое содержание:

Целью работы является подчеркивание преимуществ при применении математического моделирования в проектировании и разработке новых решений или оптимизации существующего объекта. Представлены основные принципы моделирования без изложения подробной математической модели, из чего следует, что модель включает в себя множество неизвестных или приблизительно известных параметров, соответственно модель прозрачного кибернетического ящика исключается. Для того чтобы достичь синтеза моделей и экспериментальных результатов необходимо применение методов оптимизации для идентификации неизвестных параметров модели.

В статье представлены экспериментальные результаты наряду с результатами моделирования, а также анализ результатов процесса идентификации неизвестных параметров модели.

Ключевые слова: дизельный двигатель, система впрыска топлива, математическое моделирование, идентификация.

МАТЕМАТИЧКО МОДЕЛИРАЊЕ И ИДЕНТИФИКАЦИЈА ПАРАМЕТАРА МАТЕМАТИКОГ МОДЕЛА СИСТЕМА УБРИЗГАВАЊА ГОРИВА КОД ДИЗЕЛ МОТОРА

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ЈЕЗИК ЧЛАНКА: енглески

Сажетак:

Циљ рада је да се истакну, ако не све, а оно бар најважније предности које доноси примена математичког моделирања током пројектовања новог решења или усавршавања и оптимизације постојећег објекта. Изложени су основни принципи израде модела без изношења детаљне математичке интерпретације процеса из чега следи да модел садржи већи број непознатих или орјентационо познатих параметара и да није могуће реализовати модел типа прозирне кибернетичке кутије. Да би се остварила синтеза модела и експерименталних резултата неопходна је примена оптимизационих метода за идентификацију непознатих параметара модела. У раду су наведени експериментални резултати упоредо са резултатима моделирања и идентификације као и анализа поступка идентификације непознатих параметара модела.

Кључне речи: дизел мотор, систем за убризгавање горива, математичко моделирање, идентификација.

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SMART FIELD ARTILLERY INFORMATION SYSTEM: MODEL DEVELOPMENT WITH AN EMPHASIS ON COLLISIONS IN SINGLE SIGN-ON AUTHENTICATION

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Abstract:

This paper proposes a model for a Smart Field Artillery Information System (SFAIS) that can be used in a military environment. It is based on Service Oriented Architecture (SOA) and Command, Control, Communications, Computers, and Intelligence Information Systems (C4I), as well

as Geographical Information System (GIS) technology. The system aims to contribute in increasing the level of the military's capacity in the execution of operations in a multinational or a regional environment. In this context, the SFAIS provides a well-designed platform for interoperability with other actors in the same theater of military missions and joint operations. Moreover, the system will be used for educational purposes by being implemented in simulation centers and computer laboratories. This system will provide artillery personnel with proper education which will rely on - and is going to be conducted in - a simulated operational environment which will include the whole operational range of the artillery systems used (field of fire) and the process of preparation of the elements as well as conducting the firing in a virtual environment. Additionally,and even more importantly, the probability of collisions in hash functions during Single Sign-on authentication is presented for proving existing security shortcomings in distributed computer systems. Also, studying specific security issues with the SOA based artillery information system emphasizes the significance of applying a military information system in a security environment.

Key words: authentication, single sign-on, GIS, hash function, artillery, service oriented architecture, security, military, information systems.

Introduction

Field operations require a good understanding of the characteristics of the operational environment. Prior to using modern Information Technology (IT) systems, field crews relied exclusively on the guidance from a person that is familiar with the operational surrounding. If the teams or individuals were dispatched in a zone where the field activities were to be conducted without proper guidance, complex calculations needed to be performed using paper maps, compass and other devices in order to navigate and to fulfill the mission objective. Nowadays, with the development of contemporary Command, Control, Communications, Computers, and Intelligence (C4I) and Geographical Information System (GIS) solutions, organizations, companies and institutions are able to provide better support for their field crews not only in terms of navigation but in providing different spatio-temporal data including qualitative and quantitative characteristics of objects and events obtained during data collection, surveillance and intelligence activities as well. These information systems are usually tightly coupled with the Geographic Information System (GIS) which is a special type of computer-based information system tailored to store, process, and manipulate geospatial data (Worboys & Duckham, 2004) and is used to support command and control of operations starting from the tactical level up to the strategic level of armed conflict management. However,

the ability of the GIS to handle and process both location and characteristic data distinguishes the GIS from other information systems. This establishes the GIS as technologically important for a wide variety of applications (Chang, 2005), especially in the military domain. The GIS solutions are not only digital substitutions for paper maps but are becoming crucial in the integration of different information sources in a spatial context. The unique ability of the GIS to present different geo-referenced data on a map enables users to simulate different events through modeling, adjustment of data and scenarios for prediction, planning and estimation. In a spatial context, this level of information integration and presentation is difficult to achieve using any other information system. This is exactly why such systems can be and in recent times have a tendency to be used in a wide range of areas such as the security and intelligence domain, emergency management, and the military domain in particular. In a military environment, such systems are usually used for mission planning, target discovery and tracking, coordination between different military units and for weapon guidance and fire control.

In this paper, we propose a model for a specialized C4I system whose general purpose is artillery support. Considering the fact that similar systems require that geo-information as well as other types of information is accessible to a wide range of users with different responsibilities, located in different geographic locations, in addition to providing access to geospatial data for users with different levels of privileges and different responsibilities, this leads us to use Service Oriented Architecture (SOA) for developing a model of this type of system. Related work in this area is presented in the section that follows. Furthermore, the paper will deal with the phases of system development and look at the regulated access to the data that the Information system holds, in particular, the inconsistencies of using SOA regarding the probability that collisions can happen in hash functions during Single Sign-On (SSO) authentication with the stress of the Password Authentication Protocol (PAP). The expected results and conclusions are given at the end of the paper.

Related work

There are a large number of referred research papers from this area. Analyzing the relevant literature, we have come to the conclusion that in many technologically developed countries the implementation of Service Oriented Architecture in the military domain and especially in the Field Artillery Information Systems is driven by a unique reason - to enhance the

cooperation between different military actors on the battlefield and enhance their success while conducting a specific mission.

We can say with certainty that the latest achievements in the defense technology are based upon C4I (Command, Control, Communications, Computers, and Intelligence) (Worth, 2008) systems with Artillery Information Systems being a special kind of Command Information Systems (C4I) widely used by defense forces all over the World. Frequently used information systems, which support intelligence activities, have high influence in the decision making process, and modern information technology considerably contributes to the processes' improvement by supporting the intelligence cycles planning, collecting data, analyzing data and dissemination (Achkoski, et al, 2011). According to Medlow (Medlow, 2009), the interest about SOA leads to extended implementation in the information and communication systems that are a part of both the military and civil domain. However, we cannot simply implement Service Oriented Architecture (SOA) into the unchangeable infrastructure of an existing organization because there are numerous factors that can potentially complicate the implementation of SOA in the design of some systems within the military domain in spite our primary purpose being to enhance these systems (Pulier & Taylor, 2006).This is exactly why the effective implementation of SOA in the information systems of land forces detachments deployed in military, peacekeeping, post-conflict society reconstruction or any other kind of non-military jointly led missions presents a big challenge.

Radcliffe, et al. (Radcliffe, et al, 2014) conclude that the information systems for command and control that are used in the operational headquarters use SOA in order to increase the multiple actors' ability to exchange information between them. SOA's approach allows flexibility, integration, systems interoperability and increases the potential of the military actors using Commercial-Off-The Shelf (COTS) technology and standards. Moreover, this paper covers architecture modeling, SOA Governance and gives a summary of a specific multinational demonstration activity where these types of prototype services were implemented. The authors conclude that SOA solutions can be used for increasing the capability of specific actors acting in a clearly defined military environment. Furthermore, they propose developing SOA solutions of C4I information systems in every single field of the military environment.

The advancements of SOA in the development of information systems and the extent to which it helps for the effective use of directed military force is fully entailed under a program devised by the British, named: Network Enabled Capability (NEC). This problem matter is presented more clearly in (Brehm, Gómez, 2005, pp. 29-48).There we find that the

advancements of SOA can be exploited in building and designing military information systems for supporting NEC. Service orientation offers unique possibilities that ultimately change the way of exploiting information systems and with them the Ministry of Defense (MOD) departments and their operational formations can increase their efficiency.

Furthermore, from a business perspective, it is important to understand that the opportunity for the development of services focused on delivering improvements in the working capability of military actors will most certainly appeal greatly to potential customers and users. This same offer implies a solution in the form of an integrated system derived from the use of SOA planned to be used in line with the other, older information systems that are already used in the military.

Finally, this paper entails some of the exploits for SOA with the intention that the MOD will turn to using it more extensively and exploit the benefits of NEC on a higher level.

SFAIS model development

SOA presents a "next step" technology, steadily becoming a standard that inspires the re-use of information systems and loosely coupled systems. The independency of the implementation platform implies that older hardware and newer software can be replaced and updated without negative implications toward other components of a system as long as the communication interface of the service stays the same. Following the latest Information and Communication Technology (ICT) advancements, the Smart Filed Artillery Information System (SFAIS) based on SOA should be designed as a hybrid system (store-and-forward mode and real-time mode). The most recent research works and studies that address the use of SOA show that agencies, departments, institutions and other stakeholders can push and pull data in a standardized and flexible manner through the use of communication interfaces using XML schemes and web services.

The development of the SFAIS model based on SOA takes us through a number of phases. At the start, research will be focused on the wider "Information Technology and Military" expert public that will be asked to describe multiple solutions for information systems which will serve best and are related to the functions of artillery units. Because of the model sensitivity, this research will be focused on academic and unclassified sources, as well. As soon as that is done, an analysis whose purpose will be to make a conclusion about the benefits of modeling SOA based systems will take place in order to further strengthen the statement that SOA is the technological choice that

surpasses all other technological solutions for designing information systems of the C4I sort.

The actual design of the prototype starts with the development being focused on creating the basic system modules:

1. GIS Module - necessary for unit deployment in the operation planning phase when a specific artillery unit is being assigned a mission. The module presents the user with multiple variants of choice for deploying field artillery units (the combat component of artillery units) based on predefined parameters such as: deployment of the artillery battery combat elements – depending on the type of artillery weapon and deployment of the artillery division combat elements – depending on the type of artillery battery.

2. GIS based Forward Observer module - necessary to provide input data to the system. This module will be later used for further system development and testing. The Forward Observer (FO) module provides the user with basic functions for: marking positions of friendly and enemy units on a digital map, marking targets, targeting data, and transfer of target and fire mission data over the military network.

Figure 1 – Example from the mobile GIS Forward Observer module (the crossed, red, diamond shaped signs describe an enemy infantry unit)
Рис. 1 – Пример с модуля мобильной географической системы для поддержки артиллерии (маркировка в виде крестика, красного цвета и красного ромба обозначает пехотное подразделение противника)
Слика 1 – Пример из модула мобилног географског информационог система за артиљеријску подршку (ознаке у облику крста, црвене боје и дијаманта описују непријатељску пешадијску јединицу)

As a result of using the system modules, the possibilities of providing accurate information for deploying artillery weapons on the ground, especially in the region where artillery combat elements are scheduled for deploying, increase significantly (Figure 1). However, to calculate variables in the system module, the user will need to enter the following parameters: artillery weapon type, weapon caliber, ammunition type, region of targets, meteorological data, and other parameters. These parameters are a part of a different, Ballistic Module integrated within the Smart Field Artillery Information System, as shown in Figure 2.

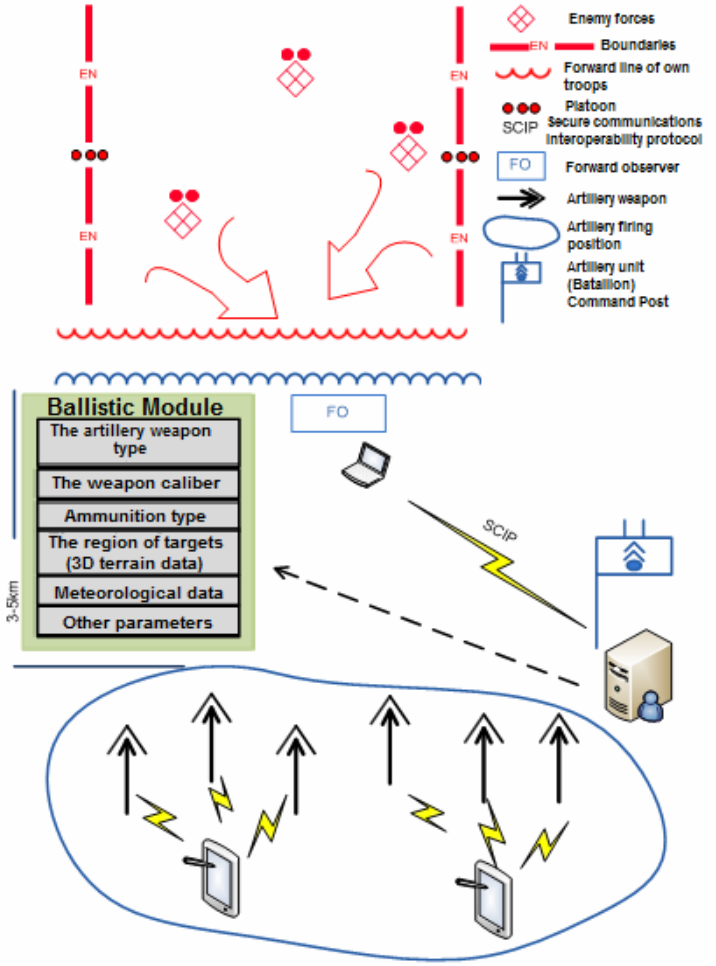

Figure 2 – Concept of the Smart Field Artillery Information System
Рис. 2 – Концепт интеллектуальной информационной системы полевой артиллерии
Слика 2 – Концепт паметног информационог система пољске артиљерије

Additionally, as the system development progresses on, a mathematical model will be defined and a Software Module will be designed to compute the initial or preparatory elements needed to direct the artillery fire. This module has different options (arranged in multiple optional categories) to choose from in order for the user to direct artillery fire while having the opportunity to select the type of weapon, the type of unit, and other options, which are important and must be taken in consideration to conduct a successful artillery firing.

The first category includes the subsystem for computing the preparatory or initial firing parameters for the artillery battery equipped with a certain type of weapon. The second category includes the subsystem for computing the initial firing parameters for an artillery division, which depends on the types of weapon within the different artillery batteries. The third category includes the sub-system for computing the parameters for subsequent corrections or the so-called adjusting of the artillery fire.

Moreover, a software module for the calculation of used ammunition per one artillery fire shooting will also be a part of the SFAIS. The module development automates the process for calculating used up ammunition. Furthermore, the module is connected to a military logistic information system that will provide timely reporting for used ammunition per firing and plan for timely supplying the artillery unit with the type of ammunition needed.

Finally, a protocol for exchanging information between the Forward Observer, the Fire Direction Center (FDC) and the Tactical Operational Center (TOC) will be used to channel information for exchange between these three pivotal actors on the battlefield. This information will provide a better visualization of the targets; it will fulfill the logistic requirements on time; it will help manage the human resources better, as well as significantly help the successful execution of the mission and operations.

In summary, developing the SFAIS would mean achieving the following goals in the field of directing artillery fire:

• Standardized protocol for exchanging information needed for achieving successful fire support;

• A defined application model that is easily integrated with other information systems that are not based on the service-oriented paradigm. Here we are avoiding the technical dependence for developing a field artillery information system relying only on one technology and, on the contrary, we are bringing in the possibility of integrating different information systems that are based on different platforms (Distributed Component Object Model – DCOM; Common Object Request Broker Architecture – CORBA; Remote Procedure Call – RPC; Remote Method Invocation - RMI);

Manev, N., et al, Smart field artillery information system: model development with an emphasis on collisions in Single Sign-On authentication, pp. 442-463

• A defined Integral Ballistic mathematical model for directed artillery fire which includes a weapon model, an ammunition type and ballistic parameters, meteorological data and a 3D terrain model;

• Integration of security mechanisms and a selection and description of security standards that should be used in the SFAIS in order to achieve an appropriate level of the access control;

• Defined metrics for the evaluation of the services related to the Field Artillery Unit implemented over service oriented architecture;

• Defined specific methodology for meteorological parameters determination based on the attenuation of electromagnetic waves in the atmosphere;

• Implemented desktop and mobile GIS front-end application for the visualization of SFAIS data.

Probability of collisions in hash functions during Single Sign-On authentication

Taking in consideration that the basis for the SFAIS prototype is Service-oriented architecture, we cannot stress enough the importance of looking at the pros and cons of using SOA as a platform for this system. Although SOA gives an unobstructed access to all actors with a specific clearance on using data, at the same time, as a platform, it faces a certain probability that collisions can happen in hash functions during Single Sign-On (SSO) authentication with stress on the Password Authentication Protocol (PAP). It means that clients (in a distributed computer system) or, in our case, actors on the battlefield with different privileges, can have access to services and resources that they are not authorized to use. To be more precise, what this means is that the distributed information system follows the well known matrix (*Table 1*) about the Discrete Authorization Control (DAC) system, a case where collisions that can happen in the system will cause the problem with the authentication and authorization in terms of system privileges that user have or do not have. Having stated that, here we are going to find the value of probability that depends on the length of the key (password) and the number of users in the system, where the results will be implemented in the PAP.

The Access Control Matrix (ACL) has subjects and objects. The subjects in the ACL are the users of the distributed system, in our case the users of services, where *S* is a row for every subject in the matrix. The objects in the ACL present system resources, where *O* is a column for every object in the matrix. The access allowed by the subject *S* to the object *O*

is stored in the intersection of the row indexed by *S* and the column indexed by *O*.The privileges in the system are shown in Table 1.

Table 1 – Access Control Matrix about Discrete Authorization Control (DAC);
x - execute; w - write; r - read; a - append
Таблица 1 – Матрица контроля доступа к дискретной авторизации (DAC);
x - исполнить; w - записать; r - прочитать; a - дополнить
Табела 1 – Матрица контроле приступа о контроли дискретне ауторизације (DAC);
x – извршити; w – написати; r – прочитати; a – додати

	/mail/Person X	edit.exe	db.exe
WS -1	{r, w}	{r, x}	{r, w, x}
Person X	{}	{r, w, x}	{w, x}
WS - 2	{a, r}	{}	{r, x}
. . .			
WS -N	{r, w}	{r, x}	{r, w}

The previously mentioned problem about collisions in the hash functions can be proven with the cryptography problem called *"birthday paradox"* as presented by (Batista, et al, 2012).The simplest way of presenting the security implications of hashing is with the question: How many people *K* out of *N* in one room have the same birthday as you if the probability is greater than 1/2? In order to find the probability *P(K)*, it is easier to compute the probability $\overline{P}$ of the number of people *N* that do not have the same birthday as you. The aforementioned authors come up with the following equations:

$$P(K) = 1 - e^{-\frac{N^2}{2*365}}$$

$$\ln 1 - \ln 2 = -\frac{N^2}{2*365} \Rightarrow N^2 = 2\ln 2 * 365$$

$$N = \sqrt{2\ln 2} * \sqrt{365} = 1.774 * 19.1045 = 23 \quad (1)$$

As far as the *"birthday paradox"* goes, we can conclude that 23 people in the room are enough to expect finding at least two or more people out of N to have the same birthday.

But, in addition to this, the *"birthday paradox"* can be exploited in computing the probability *P* of attacking the hash function, where the hash function *h(x)* generates an output of *N* bits long. In this case, the possible values of *N*, when *N* is used in the hash function *h(n)* , is 2^N, because *N*

could be either 0 or 1. Since $\sqrt{h} = \sqrt{2^N} = 2^{N/2}$ and if we hash about $2^{N/2}$ different inputs, we can expect to find a collision, that is, have two inputs that hash to the same value.

For example, if we want to find the work that needs to be done in order to break the hash function with a probability of 0.5 for generating a collision with brute force, where the input is the hash function with 32 *bits*, then we need to compute:

$$N(0.5, h) \approx 1.1774 * \sqrt{h} \Rightarrow$$

$$\Rightarrow 0.5 - \text{Probability to break hash function}, \sqrt{h} = 2^{N/2}$$

$$N\left(\frac{1}{2}, 32\right) \approx 1.1774 * 2^{\frac{32}{2}} = 1.1774 * 2^{16} = 1.1774 * 65536 = 7.7 * 10^4 \qquad (2)$$

Finally, we need to discuss the collisions that can happen with brute force with different values of probability that depend on the number of *n* bits in the hash function *h(n)*. In this case, we are looking at two cases (Case A and Case B). The numbers of bits that are used in these cases are 64, 80, 128 and 160 *bits*. The particularity in the selection of using these numbers of bits refers to the standard length of a password, which means that 8 characters is the standard length of a password. However, the user can choose from 256 possible characters from the keyboard. The choices that the user has can be presented as 256^8. This number is equal to 2^{64} hash function *h(n)* or it is a 64-bit cryptographic key, hence the reason for choosing $n = (64, 80, 128, 160)$ as a length for the hash function *h(n)*.

To illustrate the real time working capability of a SOA platform as well as the hash function application, it is best to provide a real-life example of an Information system whose access is open only to users with a specific clearance, authorized by an account and a password.

Example: Let us suppose that we designed a multi user information system based on service-oriented architecture. The information system is accessed by multiple users based on their account and their password. If the system administrator records the accounts and passwords in a separate file in the information system, then the level of threat is too high. One of the solutions to this problem is saving user names and passwords that are hashed with a certain hash function *h(n)* in a separate file. Let us assume that the hash function *h(n)* is an ideally and perfectly chosen function, where *h* maps each valid input into a different hash value $\{0.,1\}^* = \{0.,1\}^k$. This means that users access the system with *n* passwords and the Information system allows access to the user in the system only if the hash va-

lue *h(n)* can directly locate the record in the file where the hash values are stored.

Case A: If we have an attacker (a regular user) that has the intention of accessing the computer system as a system administrator (super user) generating random passwords (avoiding duplication of passwords that are used once), what are the minimum numbers of passwords *(N)* that the attacker can try to guess correctly?

To explain Case A in an appropriate manner, the following assumptions are introduced:

$$n = 64 bits \ ; \ P = 25\% \ ; \ P = 50\% \ ; \ P = 75\% ; \ P = 99\%$$

To determine the probability of collisions, when the password is 64 bits long, we have to compute the following expression:

$$P = 99,9\%; \ n = 64 bits \Rightarrow h = 2^{64}$$

$$\Rightarrow 0.99 = 1 - e^{-\frac{N^2}{2h}} \Rightarrow 0.01 = 1 - e^{-\frac{N^2}{2h}} \ / ln$$

$$\ln 0.01 = -\frac{N^2}{2h} \Rightarrow N^2 = -2 * \ln 0.01 * h$$

$$\ln 0.01 = -4.605170185988091 \approx -0.4606$$

$$-2 * \ln 0.01 = -2 * (-4.606) \approx 9.212$$

$$N = \sqrt{9.212} * \sqrt{h} = 3.035 * \sqrt{2^{64}} = 3.035 * 2^{32} = 3.035 * 4.3 * 10^9 = 13.05 * 10^9$$

Table 2 showcases the results for the desired probability when the passwords are 64 *bit* long. The intention is not to show how the process of computation is done and that is the reason that we show only how the probability is computed with 99%. Since the same equation can be used in order to calculate the desired probability when the passwords are 64, 80 and 128 *bits* long, the results in the remaining 3 cases are respectively presented within Table 2, as well.

Table 2 – The results of the desired probability when passwords are 64, 80, 128 and 160 bits long
Таблица 2 – Результаты предполагаемой вероятности, в случае длинных паролей 64, 80, 128 и 160 битов
Табела 2 – Резултати жељене вероватноће када су лозинке дугачке 64, 80, 128 и 160 бита

	Probability of collisions with the brute force attack			
Number of bits	$\left(\frac{1}{4}\right)25\%$	$\left(\frac{1}{2}\right)50\%$	$\left(\frac{3}{4}\right)75\%$	99%
64	$3.3*10^{9}$	$5,06*10^{9}$	$7.2*10^{9}$	$13.05*10^{9}$
80	$0.82*10^{12}$	$1.28*10^{12}$	$1.8*10^{12}$	$3.3*10^{12}$
128	$1.4*10^{19}$	$2.2*10^{19}$	$3.1*10^{19}$	$5.46*10^{19}$
160	$0.60*10^{24}$	$1.41*10^{24}$	$1.99*10^{24}$	$3.6*10^{24}$

In response to the conclusion we have made earlier, let us repeat that the number of bits used in these cases are 64, 80, 128 and 160 bits. The particularity in the selection of using these numbers of bits refers to the standard length of a password, which means that 8 characters is the standard length of a password. However, the user can choose from 256 possible characters from the keyboard. The choices that the user has can be presented as 256^8. This number is equal to 2^{64} hash function *h(n)* or it is a 64-bit cryptographic key; hence the reason for choosing $n=(64,80,128,160)$ as a length for the hash function *h(n)*. Accordingly, a graphic presentation is given for each and every possibility of a 64, 80, 128 or 160 bit password length in Figures 3, 4, 5, and 6, respectively. Figure 7 gives a cumulative graphic presentation of the password length of *n* = (64,80,128,160) *bits*.

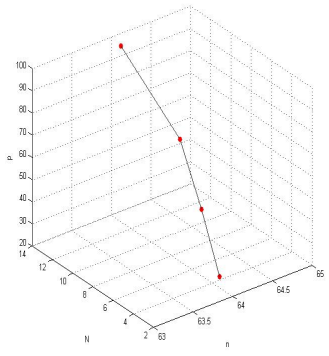

Figure 3 – A 3D graphic presentation for the password length of *n = 64 bits*
Рис. 3 – 3Д графическое изображение пароля размером *n = 64 битов*
Слика 3 – 3Д графичка презентација за лозинку дужине *n = 64 bits*

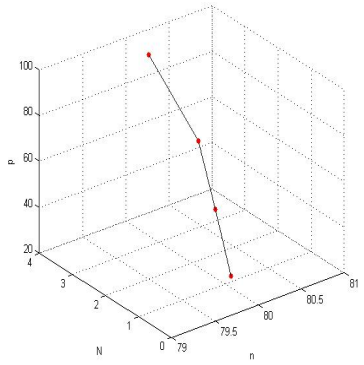

Figure 4 – A 3D graphic presentation for the password length of *n = 80 bits*
Рис. 4 – 3Д графическое изображение пароля размером *n = 80 битов*
Слика 4 – 3Д графичка презентација за лозинку дужине *n = 80 bits*

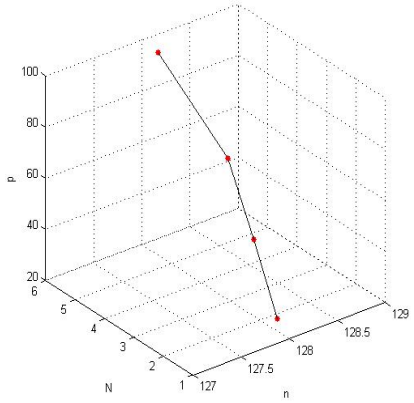

Figure 5 – A 3D graphic presentation for the password length of *n = 128 bits*
Рис. 5 – 3Д графическое изображение пароля размером *n = 128 битов*
Слика 5 – 3Д графичка презентација за лозинку дужине *n = 128 bits*

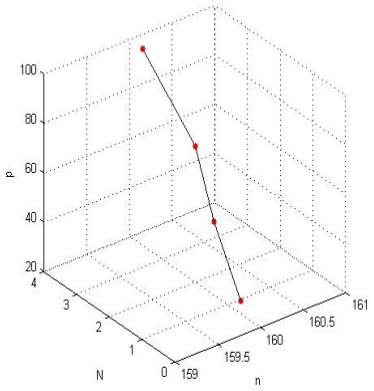

Figure 6 – A 3D graphic presentation for the password length of *n = 160 bits*
Рис. 6 – 3Д графическое изображение пароля размером *n = 160 битов*
Слика 6 – 3Д графичка презентација за лозинку дужине *n = 160 bits*

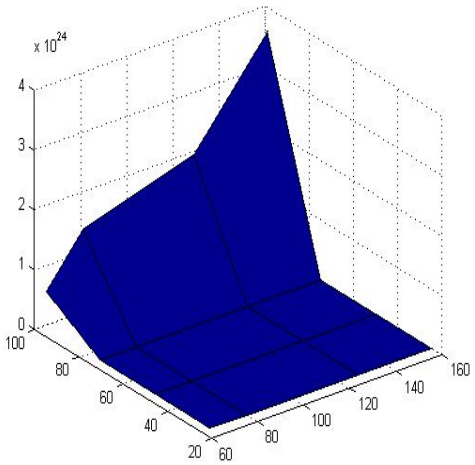

Figure 7 – A 3D graphic presentation for the password length of *n = (64, 80, 128, 160) bits*
Рис. 7 – 3Д графическое изображение пароля размером *n = (64, 80, 128, 160) битов*
Слика 7 – 3Д графичка презентација за лозинку дужине *n = (64, 80, 128, 160) bits*

Additionally, we created a pseudo code for computing collisions in the hash function that can help optimize the process for gathering value of trays that depend on the probability and bits in the hash function.

Computing collisions(){

declare variables (){

variable P;

input $P = (0,\ldots,1)$;

variable n;

input $n = (0,\ldots,n-1,n)$;

}

compute $h(n)$ (){

$h(n) = 2^n$

return $h(n)$;

}

initialize computation(){

$$P = 1 - e^{-\frac{N^2}{2*h}}$$

do substraction () {

$$e^{-\frac{N^2}{2*h}} = 1 - P$$

$$e^{-\frac{N^2}{2*h}} = P'$$

if (P' *is greater than* 1){

Print " *Algorithm failed* "

else{

if (P' *is less or equal to* 1){

Print " *Continue with computation* "

}

}

return P'

}

start natural logarithm function (){

$\log_e x = \ln x$;

$$e = 2.718;$$

divide expression with natural logarithm ln (){

$$e^{-\frac{N^2}{2*h}} = P' \ / \ \ln$$

$$\ln P' = -\frac{N^2}{2*h}$$

return P'

}

compute expression(){

$$2 * \ln P' * h = -N^2$$

$$N^2 = -2 * \ln P' * h$$

$$N = -\sqrt{2 * \ln P'} * \sqrt{h}$$

compute : $-\sqrt{2 * \ln P'} = a;$

compute : $\sqrt{h} = 2^{\frac{n}{2}} b;$

return a, b ;

replace a *and* b ;

$N = a * b;$

return N;

}

END

Case B: What is the maximum number of users *(N)*, when the probability of a collision with brute force happening in the system is under 0.05%? It means that the probability of a hash function, where every pair of users has the probability of matching passwords, is equal to 0.05% .

To compute the number of users in the system with certain probability of collisions with brute force in Case B, we have introduced the following assumptions:

1) $n = 64 bits \ ; h = 2^{64} \ ; P = 0.05\% \ ; N(0.05\%) = ?$
2) $n = 80 bits \ ; h = 2^{80} \ ; P = 0.05\% \ ; N(0.05\%) = ?$
3) $n = 128 bits \ ; h = 2^{128} \ ; P = 0.05\% \ ; N(0.05\%) = ?$
4) $n = 160 bits \ ; h = 2^{160} \ ; P = 0.05\% \ ; N(0.05\%) = ?$

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Consequently, Table 3 portrays the maximum number of users in the system to avoid collisions while *P = 0.05%* and Figure 8 relates to these results.

Table 3 – The maximum number of users in the system to avoid collisions, while *P = 0.05%*
Таблица 3 – Максимальное количество пользователей в системе, установленное с целью предотвращения коллизий, при *P = 0.05%*
Табела 3 – Максимални број корисника у систему да би се избегле колизије када је *P = 0.05%*

	Association of the number of bits in passwords and number of users in correlation with limited probability of collisions			
Limited Probability of collisions with the brute force attack	64	80	128	160
0.05%	$1.3*10^{9}$	$0.34*10^{12}$	$0.59*10^{19}$	$0.39*10^{24}$

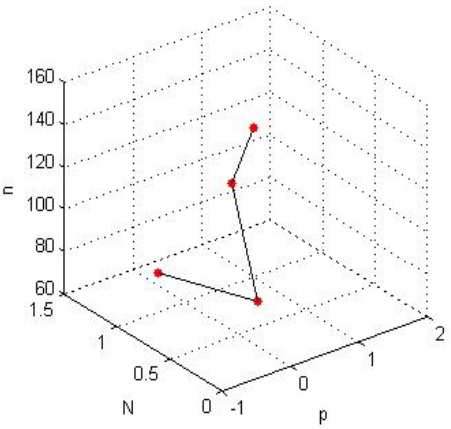

Figure 8 – A 3D graphic presentation for maximum number of users with *P = 0.05% and n = (64, 80, 128, 160)*
Рис. 8 – 3Д графическое изображение количества пользователей при *P = 0.05%* и *n = (64, 80, 128, 160)*
Слика 8 – 3Д графички приказ за максимални број корисника када је *P = 0.05%* и *n = (64, 80, 128, 160)*

Conclusion

On the positive side, innovations are tightly related to this system's creation because they refer to the shift from a traditional way of directing artillery fire into a contemporary and technologically sophisticated way of directing artillery fire. The system makes most of the processes automatic in the moment of firing from a field artillery unit deployed in the battlefield. In that manner, the field artillery units which will be equipped with SFAIS will be capable of opening artillery fire on predefined and planed enemy targets far more effectively, increasing the probability of getting an accurate artillery shot on target, excluding errors caused by the human factor during the process of preparing and entering the parameters for directed fire.

Moreover, implementing the SFAIS prototype in field artillery units is going to contribute to increasing the level of military capability while executing operations in a multinational or regional environment. In the same context, SFAIS is providing a well-designed platform for interoperability with other actors in the same theater of military missions and joint operations. The system will also make a new and significant contribution in joint operations and homeland security through the possibility of exchanging information in an appropriate way, decreasing the time for fire support in military operations and missions, disseminating information to authorities enhancing the decision-making process and taking appropriate actions, all in a faster and more reliable manner.

In addition, the system will be exploited for educational purposes. Implementing it in simulation centers, computer laboratories and other facilities will provide affordable education for artillery personnel by simulating field artillery firing and executing the process of firing in a virtual environment. Artillery officers, cadets and other personnel from the artillery branch will not need to use real time artillery weapons, military training fields and other equipment, because the system will allow the training for directing artillery fire to be executed in a lab or in a simulation center. As a result, this will allow for the justified promotion of field artillery experts capable of bringing timely and accurate decisions for resolving situations

On the "not entirely" negative side, the computation of probability of collisions in hash functions demonstrates the weaknesses in the system security, where user who do not have privilege can access system resources. We can firmly conclude that the collisions in hash functions during an SSO authentication are possible and likely to happen, but the results for finding a collision and breaking the hash function *h(n)* show that a lot of work has to be done. The work of finding collisions in hash functions is

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equivalent to the work of a brute force exhaustive key search. However, the results of our theoretical research prove that the probability of collisions in the system can decrease the level of security in the system, but this is easily overcome by the users who do not select random passwords and follow the guidelines for PAP.

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ИНТЕЛЛЕКТУАЛЬНАЯ ИНФОРМАЦИОННАЯ СИСТЕМА ПОЛЕВОЙ АРТИЛЛЕРИИ: РАЗРАБОТКА МОДЕЛИ С АКЦЕНТОМ НА КОЛЛИЗИИ В АУТЕНТИФИКАЦИИ SINGLE SIGN-ON

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ОБЛАСТЬ: КОМПЬЮТЕРНЫЕ НАУКИ, IT
ВИД СТАТЬИ: оригинальная научная статья
ЯЗЫК СТАТЬИ: английский

Резюме:

В данной статье представлена модель интеллектуальной информационной системы полевой артиллерии (SFAIS), разработанная для военных целей и основанная на сервисно-ориентированной архитектуре (SOA), а также на C4I информационной системе и технологии географической информационной системы (GIS). Цель внедрения системы заключается в повышении уровня мощности вооруженных сил при выполнении операций в рамках многонациональных или региональных действий.В этомпланеSFAIS обеспечивает хорошо спроектированную платформу для взаимодействия с другими участниками совместных военных миссий вколлективных операциях.

Система разработана для применения в центрах моделирования и симуляции, а также в лабораториях. Данная система будет применяться в учениях артиллерийских подразделений, в смоделированных операционных условиях, которые включают целый спектр артиллерийской системы (артиллерийский огонь), а также наводку орудий и выполнение огневых задач в виртуальных условиях.

Наряду с вышеперечисленными задачами, будет представлена вероятность коллизий в хешировании приSingleSign-on аутентификации, с целью выявления недостатков в системе безопасности компьютерных сетей.

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Исследования специальных параметров по безопасности артиллерийской информационной системы основаны на сервисно-ориентированной архитектуре, что в свою очередь подчеркивает значимость применения информационной системы военной безопасности.

Ключевые слова: аутентификация, single sign-on, GIS, хеширование, сервисно-ориентированная архитектуря, безопасность, вооруженные силы, информационные системы.

ПАМЕТНИ ИНФОРМАЦИОНИ СИСТЕМ ПОЉСКЕ АРТИЉЕРИЈЕ: РАЗВОЈ МОДЕЛА С ТЕЖИШТЕМ НА КОЛИЗИЈЕ У SINGLE SIGN-ON АУТЕНТИФИКАЦИЈИ

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Сажетак:

У раду се предлаже модел паметног информационог система пољске артиљерије (SFAIS) за примену у војне сврхе. Заснован је на сервисно оријентисаној архитектури (SOA), као и на C4I информационим системима и технологији географског информационог система (GIS). Циљ система јесте да допринесе повећању нивоа капацитета војске при извођењу операција у мултинационалном или регионалном окружењу. У том контексту SFAIS обезбеђује добро пројектовану платформу за интероперабилност с осталим учесницима заједничких војних мисија и здружених операција. Штавише, систем ће бити коришћен за едукацију у центрима за симулацију и компјутерским лабораторијама. Артиљерцима ће обезбедити едукацију засновану на симулираном оперативном окружењу, у којем ће се и изводити, а

које ће обухватати читав операциони спектар артиљеријских система (артиљеријске ватре), као и процес припреме елемената и извођење гађања у виртуелном окружењу. При томе ће, што је још важније, представити вероватноћу колизија у хеш функцијама током single sign-on аутентификације како би се показали постојећи сигурносни недостаци у дистрибуираним компјутерским системима. Проучавање специфичних сигурносних момената код артиљеријског информационог система, заснованог на сервисно оријентисаној архитектури, такође истиче значај примене војног информационог система у сигурносном окружењу.

Кључне речи: аутентификација, single sign-on, ГИС, хеш функција, артиљерија, сервисно оријентисана архитектура, сигурност, војска, информациони системи.

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ПРЕГЛЕДНИ ЧЛАНЦИ
ОБЗОРНЫЕ СТАТЬИ
REVIEW PAPERS

VULNERABILITY ASSESSMENT AND PENETRATION TESTING IN THE MILITARY AND IHL CONTEXT

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Abstract:

Vulnerability assessment and penetration testing are the key activities of information security risk management and cyber defense and intelligence done by military organizations. These activities are significant not only in the context of performing military operations, but also in the International Humanitarian Law (IHL) and law enforcement contexts. The application of information technologies in the military and civilian environments increases complexity in the field of risk management. Besides information security, military organizations have the task to undertake necessary activities in the fields of cyber operations, both for defense and offense purposes. They depend on technologically based knowledge and skills and are implemented by specific organizations within military systems. The goal of vulnerability assessment is to discover and determine the nature of vulnerabilities, without considering how they may be used for offense, while penetration testing uses exploits for breaching into systems and thus estimates the type and degree of risk these vulnerabilities represent to the system. However, even if they represent two different activities, with different end goals but the same field of interest, they are complimentary and inter-dependent. Since their common feature is development of knowledge and skills based on the same technologies, they are equally important both for risk management, military operations in cyberspace and their use for defense and intelligence activities as well as for IHL.

Key words: vulnerability assessment, penetration testing, cyber attack, International Humanitarian Law.

Introduction

Significance and influence of information technologies in all modern organizational and technical systems is obvious and ever growing. Military organizations require application of reliable and efficient technical systems for performance of their basic function – defense, both in peace time and during war. In modern armies, such characteristics are mostly enabled by the application of independent and embedded information technologies. No matter whether these technologies are used in military equipment and armament or for establishing and functioning of military organizational systems and their networks (command, control, and support), the use of information technologies is significant, obvious and increasing.

Comprehensive applications of information technologies and abilities of system and processes networking are so extensive that this caused a creation of a completely new, fifth domain of military activities – cyber space, which represents: "A global domain within the information environment consisting of the interdependent networks of information technology infrastructures and resident data, including the Internet, telecommunications networks, computer systems, and embedded processors and controllers." (US Army Joint Staff, 2013, p.5). Within the information domain, cyber space is characterized by the application of different types of information technologies (analogous and digital electronic, opto-electronic and even quantum technologies). The information domain consists of physical, information (including logical), and cognitive dimensions or layers (U.S. Army Joint Staff, 2014). This means that within the complete cyberspace there are different factors and elements which perform activities and they represent the basis of the cyberspace infrastructure: people, hardware, software, environment, power, networks, payload, and policy (Rauscher, 2004). These elements can be put into three key sets that constitute cyberspace, including its part used by military organizations: people, processes and systems (Godwin, et al, 2014).

Vulnerability assessment and penetration testing in the military environment

Along with the already mentioned importance of information technologies for the operation of military organizational systems and their interconnectedness within cyberspace, cyber infrastructure is crucially important to all vital services, sustainable operations and restorations of cyberspace and organizations and systems that are using it to achieve the-

ir purpose (Godwin, et al 2014). The key factor for their safe operation is protection from threats (internal or external) across all the mentioned layers. This relates not only to military systems, whose basic function is national defense, but also to all governmental and private organizations as well as individuals. This is why violation of information security often simultaneously relates to different legally regulated forms of security (national defense, but also all types of crime, including terrorism and espionage). The circumstance that conflicts in cyberspace are based on discovery and exploitation of vulnerabilities and deficiencies makes their legal regulation significantly more complex. There are so many threats that entities in charge of defense of a system cannot even perceive their total number and scope. The existing threats are changing and evolving in time, along with the development of the immediate and wider environment. They are especially extensive in the field of information security, given the numbers and variety of technologies in modern global environment, as well as mutual connections between factors that influence all phases of the information system life cycle (Donohoe, 2012). Threats are directly connected to vulnerabilities and weaknesses of a system, whether they are known to its defenders or not. In the field of information security, there is a constant and endless race between attackers and defenders that consists of competing who will be the first to discover vulnerabilities or weaknesses of a system, across every layer of the information domain (physical, information and logical and cognitive levels). Causes for these vulnerabilities are numerous and can be found at all levels of creation, use and delayed effects of these technologies; they can be grouped in several general categories:

a. Due to growing requirements for resource optimization, military systems use the same or similar information technologies as civilian structures. These commercial off-the-shelf (COTS) technologies, whether proprietary or open source, are available to everyone, defenders and attackers alike.
b. A complex supply chain of information technologies and globalization make certain segments of these technologies so connected and intertwined that causes of vulnerabilities in them can be found even in technologies created specifically for military systems (Mattern, 2015).
c. Number and scope of information technologies that oftentimes are not harmonized with each other in all elements cause occurrence of new vulnerabilities that appear during interaction between these technologies.
d. General digitalization of everything and fast expansion of information technologies cause an increasing number of

information infrastructure parts or elements that influence this infrastructure to become subject to the existing vulnerabilities.

These vulnerabilities cause asymmetry of conflict in cyberspace. Since they are subject to (purposeful or accidental) revealing and exploitation by any attacker, the number of potential conflict participants grows rapidly, both attackers and defenders. The existence of vulnerabilities makes even the biggest systems subject to actions of small groups, even individuals. Today, there is a frequent situation where military forces of foreign governments can attack private companies in other countries, like in the case of Sony (Nakashima, 2014), or that the biggest countries can take legal and political measures against individuals as U.S. President Obama ordered in April 2015 (Executive Order: Blocking the Property of Certain Persons Engaging in Significant Malicious Cyber-Enabled Activities) (Obama, 2015).The consequence of this is increasing the number of potential conflicting actors and extremely complex conflict environments.

What are vulnerabilities?

When causes of susceptibility to threats are considered, it is important to state what vulnerabilities are and how they occur. According to the National Information Assurance (IA) Glossary (Committee on National Security Systems, 2010), vulnerability is "weakness in an information system, system security procedures, internal controls, or implementation that could be exploited by a threat source". According to Herrmann (2007), whether accidental or intentional, vulnerability is a weakness that can occur in security requirements, system design, implementation, installation, operational procedures, configuration, and concurrent physical and personnel security controls, which makes this system susceptible to threats. In most general sense, in relation to the status of exposure to threats, vulnerability is absence of safeguard (Everetts, 2015).

Vulnerabilities lie in the basis of information security. According to the following conceptual equation, they are the basic risk factor in the field of information security:

$$Level\ of\ Risk = \frac{(Threats \times Vulnerabilities)}{Countermeasures} \times Impact$$ (Everetts, 2015)

This means that by discovery, removal or utilization of vulnerabilities, risk management can be universally influenced for the reduction of risks (prevention and mitigation of attacks), but also for the utilization of the existing risks of the adversary (for offensive activities, such as attacks or cyber exploitation). All these activities are achieved by influencing informa-

tion security, regardless of whether they are legally characterized as crime or armed conflict and regardless of whether they relate to defense or offense.

In defense, discovering vulnerabilities is the central part of risk assessment, involving analyses and evaluations which weaknesses and enemy activities may cause a negative influence on an organization and to what extent (Committee on National Security Systems, 2010, p.61). This activity is so significant that it represents a part of every Risk Management Framework. According to the recommendation of the National Institute for Standards and Technology (NIST), a vulnerability-oriented risk analysis should be a part of every risk management program (Cyber Intelligence Task Force, 2014), (NIST, 2012). Its goal is to maximally reduce the attack-surface model consisting of all possible layers of cyberspace and its infrastructure (U.S. Department of the Army, 2010). This leads to a conclusion that every discovery of the adversary's attack-surface enables a greater success in undertaking offensive cyber operations.

The goal of this analysis is to discover the existing vulnerabilities in one's own system, to describe them and give the technical specifications of the necessary steps for an attacker to exploit these vulnerabilities during an attack. This process is so important that it cannot be left out in any model of the information security risk management life cycle, where it is connected with other risk management processes. It must be repeated in regular intervals during a complete life cycle of a system. This is a universal case, whether a risk management model was defined by a generally accepted international (International Organization for Standardization, 2009), national (NIST, 2011) or proprietary enterprise (Committee of Sponsoring Organizations of the Treadway Commission, 2004), standard or framework.

Every vulnerability can lead to a situation where its exploitation is possible, accidental or purposeful. If conflicting sides use the same information technologies, characterized by the same vulnerabilities, discovery and technical specifications of necessary steps for exploiting vulnerabilities can be equally used for the prevention of adversary's attacks and for attacking the adversary (if the same vulnerability exists in the defended and the attacking system). This circumstance relates the skill of cyber warfare with the art of obtaining knowledge of vulnerabilities and weaknesses in information systems (and their corresponding infrastructure).

Vulnerability assessment and penetration testing

In the process of risk management assessment, in dealing with vulnerabilities, the process of vulnerability assessment should not be confused with penetration testing. Although these two concepts are similar and highly connected, they are different in their nature. The National Institute of Standards and Technology describes penetration testing as "a test methodology in which assessors, typically working under specific constraints, attempt to circumvent or defeat the security features of an information system" (NIST, 2014, p.B-7). According to the same source, vulnerability assessment (discovery and analysis) represents a systematic examination of an information system for the purpose of determining adequacy of security measures, determining deficiencies, and finding and undertaking security measures to eliminate influence of threats and reduce risks (National Institute for Standards and Technology, 2013). Therefore, penetration testing is a specific type of assessment of an information system (usually technically oriented), implemented for the purpose of determining the existence of vulnerabilities. Penetration testing is an imitation of an adversary's activity on one's own system for the purpose of pre-emptive defense. This is why penetration testing is the one procedure that makes vulnerability assessment common for both attack and defense. The development of the penetration testing methodology is connected to professional knowledge on technology and system organization and represents the application of the information technology body of knowledge in the military environment.

Military systems are specifically security oriented, since their purpose is defense of their own systems (by military means and methods) and disabling and destruction of enemy systems. In this military business, different areas of security are simultaneously planned, applied and analyzed so that vulnerability assessment and penetration testing, (that are especially characteristic for information security in contemporary organizations), are used in all other security-related areas, from physical to information security. Having in mind the already mentioned fact that in modern times all human activities depend on information technologies and cyberspace, as well as that the information area consists of wide infrastructure in a physical, information, logical and cognitive sense, it is clear that penetration testing can be undertaken for hardware, software, people and processes and it can relate to different types of security controls (physical, organizational, and technical) (NIST, 2013).

Penetration testing relates to finding vulnerabilities in proprietary or other systems, as well as to estimating a degree of resistance that infor-

mation and organization systems has against enemy activities in relation to the time necessary for breach of defense, necessary resources and skills (NIST, 2013). This universal defense/offense method applied by military and intelligence organizations is at the same time an indispensable element and a phase of every risk management process. It consists of various techniques and methods for finding vulnerabilities, and it is a part of other, broader activities, such as security monitoring, establishment of security configuration settings, establishment of policies, strategies and procedures for secure system use. Penetration testing implemented for the purpose of defense and offense does not differ much in the technology and technical approach applied, but exclusively in goals and intentions of penetration testing practitioners, within and limited to their goals and tasks. This is why training of individuals and teams for penetration testing does not have to be implemented separately for defense and offense. It is important to point out that vulnerability assessment represents the key area for collaboration of national military and intelligence organizations in cyberspace (Cyber Intelligence Task Force, 2014). This is why the use of these activities by state bodies and institutions is significant in respect of legal regulations, in both national and international laws, especially regarding the specific application of the IHL.

Education, training and legal regulation of vulnerability assessment and penetration testing

Knowledge necessary for the implementation of vulnerability assessment and penetration testing is primarily technical in its nature and requires high specialization and experience. This is why these activities (in the civilian environment) are often implemented by external providers (NIST, 2003). In practice, it is done by intelligence agencies and other organizations that do not perform attacks on military targets, that use results of external collaborators as a service, since such testing activities require human involvement, even if automatic methods by the application of specialized software or devices are used (NIST, 2003). However, in the military environment, these activities are used for the discovery of vulnerabilities in enemy military systems or for attacks on foreign targets. This sets limitations of legal nature, due to the provisions of the Law of Armed Conflict. Protocol Additional to the Geneva Conventions of 12 August 1949 states in Article 43 that “members of the armed forces of a Party to a conflict (other than Medical personnel and chaplains“ (1125 UNTS 3, 1977, art. 43) are combatants who have the right to participate directly in hostilities. Howe-

ver, no international regulations strictly forbid civilians to take direct participation in hostilities. A group of experts in the field of international humanitarian law at the invitation of The NATO Cooperative Cyber Defence Centre of Excellence in Tallinn gave their expert opinion on participation of civilians in cyber warfare, where "Civilians are not prohibited from directly participating in cyber operations amounting to hostilities but forfeit their protection from attacks for such time as they so participate" (Schmitt, 2013, p.90).

However, according to various national laws and military rules of engagement and manuals, participation of civilians in hostilities is unlawful (for example in Canada, Côte d'Ivoire, Germany, Indonesia, Italy, Nigeria, Peru, Spain, United Kingdom, and other) (International Committee of the Red Cross, 2015). In some countries with common law tradition, such as the U.S, there are cases where in different stages of a case court decisions were made according to which participation of alien civilians in hostilities was treated as unlawful (McCarthy, 2007), because they were civilians who took part in hostilities, therefore, they were neither lawful combatants nor lawful civilians.

It is, nevertheless, necessary to point out that there is still no universal international consensus on this issue, since no treaty law nor customary law precisely define what represents direct participation in hostilities, as pointed out in the Pre-Trial Chamber of the International Criminal Court in the Case of the Prosecutor v. Bahar Idriss Abu Garda (ICC-02/05-02/09, 2010). Also, it is necessary to take into consideration the complexities of a situation where development of technology and its application in hostilities is an important factor of additional complexity of international legal regulations of conflicts in which civilians participate in one of possible ways (Schmitt, 2004). Even without this dominant factor today, the existing provisions and rules of International Humanitarian Law, some of which are more than a hundred years old, are imprecisely and unclearly defined because they were adopted through consensus of all international parties (states), which is an almost impossible task in practice due to their different interests and traditions.

The already mentioned legal reasons and requirements to achieve confidential military information secrecy in military organizations require that vulnerability assessment and penetration testing be done by members and groups from the military itself. To achieve this, it is necessary to systematically train members of the military who perform these activities. In doing this, there should be no compromises, because their training and qualifications are what key activities in cyber defense and warfare depend on. Besides requirements for top achievements, their training should be continuous, since search for vulnerabilities is a constant process that must

be improved and developed all the time. The focus during training should be put on education in relation to gaining awareness and training, since this activity is considered to be a key one within the Information Technology Security Learning Continuum for the creation of appropriate information technology security specialists and professionals (NIST, 2003; 1998). However, since these are top experts, no form of professional improvement and development should be neglected, such as advanced training and even research activities.

Need for research and development in vulnerability assessment and penetration testing

Research in the field of information security vulnerabilities and penetration testing is an especially important field, since there is the requirement that new solutions for system breach be constantly developed. Personnel must constantly be trained in new techniques and methods. This is why there must be a close collaboration between military organizations and academic research institutions, industrial research and development centers and small, private teams and even individuals. This means that asymmetry in information security for the purpose of conducting military conflicts does not reflect only in differences between enemies, but also in enlistment of collaborators. This asymmetry is enabled by high specializations in specific fields; particularly suitable for such applications are penetration testing of software systems, services and applications.

Every software contains vulnerabilities that are a consequence of errors in coding and lack of coordination in processes and interactions between different software technologies. According to McConnell, the industry average number of coding errors in 2004 was between 1-25 errors per 1000 lines of programming code and 0.1 error per 1000 lines of code in the highly efficient special development technique (2004, p.25).The same author states that in only a few known cases, primarily in the space shuttle technology, with the application of specific methods which slow down and significantly increase costs of the coding process, a success of zero errors in 500,000 lines of code was achieved (McConnell, 2004). However, history shows that even in such cases software errors go unnoticed by penetration testers, like in the case of explosion of ARIANE 5 rocket explosion in 1996 (Inquiry Board, 1996). Along with the development of new technologies, their application in complex combat systems grows. For example, the most complex multipurpose military aircraft in development, Lockheed-Martin F-35 Joint Strike Fighter, has over 24 million code lines so

far, mostly done in C and C++ languages, and their numbers continue to grow as new systems and requirements are added (Charette, 2012). In such a number of code lines, it is to be expected that there is a number of errors and lack of process coordination that might be used in the future for a cyber attack. Even before the initial exploitation of the aircraft, industrial espionage in cyberspace enabled penetration testing experts of a potential future enemy to find suitable exploits whose application might achieve kinetic consequences to combat systems in a potential future conflict (The Wall Street Journal, 2014).

Need for the formation of vulnerability assessment and penetration testing teams within military organizations

Once exploited vulnerability is easier to discover and through (ab)use it stops being suitable for a new application. It is also important to know where to look for defects and vulnerabilities, because there are differences in the number of coding defects in software written in different program languages (Ray, et al, 2014, pp.155-165). This is why attackers must be experienced and trained, because they are expected to quickly and clearly make an evaluation of a choice of vulnerability in specific situations. For example, in the report of Kaspersky company on breaches into information systems of many countries by the Equation group, there was discovered a systematic regularity on the application and hierarchy of choice of targeted systems vulnerability information in relation to their significance (Kaspersky Labs, 2015). This is why it is believed by experts that an attacker group most probably represents a unit of an intelligence agency of a technologically developed country. It is not likely that adversary vulnerability information will be used over a longer period of time. Most valuable are those vulnerabilities that are not discovered by anyone, except for attackers, in the moment of the attack. They are called zero-day vulnerabilities and are used to initiate zero-day attacks. Software or a method, a set of data, a sequence or an attack command which uses the zero-day vulnerability is called the zero-day exploit. The more software is widespread, the more interesting it is for different penetration testing teams that find new zero-day vulnerabilities. The world of penetration testing thus comes down to an eternal race between attackers, defenders and manufacturers who, for their own reasons, are all trying to discover as many vulnerabilities as possible and use them for attack or defense. Although all big softwa-

re companies pay independent researchers for information on zero-day vulnerabilities, the market for information about them is growing. It is joined by state agencies and specialized penetration testing and vulnerability assessment companies and teams which even have regular clients among agencies (Perlroth & Sanger, 2013). The most well-known are Vupen (Vupen Security, 2015), Revuln (Revuln, 2015) and Netragard (Netragard, 2015).

Even though such a collaboration model can successfully help attempts of information infrastructure protection and conducting offensive operations in cyberspace, it is not sufficient for all the needs at the national level. Within military forces, it is necessary to form groups and teams for vulnerability assessment and penetration testing that are made up of experienced and highly skilled individuals. An example of a successful organization in these activities which applies the methods and techniques described is Tailored Access Operations, a group within the National Security Agency (Aid, 2013). However, regardless of being formed as a part of a global military force or a small country army, vulnerability assessment and penetration testing organizations within armies must have their structural freedom and organizational independence from the rest of the army. Given the basic value that unites members of such teams, which is highly specialized knowledge and skills, the traditional vertical hierarchy makes their functioning and development harder and limits creativity. This is why such units are always more efficient if they follow an unconventional, problem solving-oriented organizational structure.

Conclusion

Vulnerability assessment and penetration testing are a central part of all defensive and offensive military activities in cyberspace. At the same time, they are a key part of a comprehensive process of risk management, without which compliance requirements of any information organization system cannot be achieved. Information security risk management represents organizational management of people, processes and systems. Vulnerability assessment and penetration testing are primarily oriented to information technologies and the way people interact with them. Even though these activities have the same focus, same technologies and processes, their goals are different but complementary. There are defects, flaws and weaknesses in every information system. Their nature varies widely and the number is always increasing. Information on vulnerabilities is the goal, both for the system's author and defenders and attackers and there is always a competition between these sides who will obtain the valuable

information first. Owning the same information on vulnerabilities enables the prevention of threats (external and internal), but at the same time it enables exploiting adversary's weaknesses. Due to this characteristic, vulnerability assessment and penetration testing are equally important for the risk management process, offensive and defensive military and intelligence operations in cyberspace. If, by a process of elimination, different activities in the mentioned fields of information security are removed, it is clear that its tasks cannot be achieved without vulnerability assessment and penetration testing. Their activities can be outsourced to organizations outside the military, but having in mind the confidentiality requirement and limitations set by International Humanitarian Law, it is necessary for units working on these activities to be a component of military organizations. Nevertheless, having in mind the need for specific knowledge and skills, and requirements for constant research, their organizations must be specific and set in a way so as not to be disturbed by the traditional military vertical organizational hierarchy.

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ОЦЕНКА УЯЗВИМОСТИ И ТЕСТИРОВАНИЕ НА ВЗЛОМ В ВОЕННОМ И МЕЖДУНАРОДНОМ ГУМАНИТАРНОМ ПРАВЕ

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Резюме:

Оценка уязвимости и тестирование на взломявляются ключевой деятельностью управления информационной безопасностью и рисками кибероборонь, а также разведки, проводимой военными организациями. Эти мероприятия имеют важное значение не только в контексте выполнения военных операций, но и в международном гуманитарном праве (МГП) и правоохранительных контекстах. Применение информационных технологий в военных и гражданских условиях увеличивает сложность в области управления рисками. Помимо информационной безопасности, военные организации должны проводить необходимые мероприятия в области кибероперацийь, как для защиты, так для нападения целей.

Они зависят от технологических знаний и навыков и реализуются конкретными подразделениями в рамках военных систем. Цель оценки уязвимости заключается воткрытии характера уязвимости, не анализируя, как они могут быть использованы приатаках. В то время как тестирование на проникновение использует эксплойт-вторженияво время атаки на системуи таким образом производит классификациютипа и степенириска уязвимости для системы.

Тем не менее, хотя они и представляют собой два различных вида деятельности с разнымицелями, их взаимодействие неразделимо, так как они взаимосвязаны и дополняют друг друга. Общей чертой данных мероприятий является развитие знаний и навыков, основанных на тех же технологиях, и они одинаково важны как для управления рисками в военных операциях в киберпространстве, так и в области обороны, разведки и международного гуманитарного права.

Ключевые слова: оценка уязвимости, тестирование на проникновение, кибератаки, Международное гуманитарное право.

ПРОЦЕНА РАЊИВОСТИ И ТЕСТИРАЊЕ ОТПОРНОСТИ НА УПАДЕ У СИСТЕМ У ВОЈНОМ И КОНТЕКСТУ МЕЂУНАРОДНОГ ХУМАНИТАРНОГ ПРАВА

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ОБЛАСТ: рачунарске науке, међународно хуманитарно право
ВРСТА ЧЛАНКА: прегледни чланак
ЈЕЗИК ЧЛАНКА: енглески

Сажетак:

Процена рањивости и тестирање отпорности на упаде у систем су кључне активности управљања ризиком у информационој безбедности, сајбер одбрани и обавештајном раду војних организација. Ове активности су значајне у контексту извођења војних операција, али и у контексту Међународног хуманитарног права (IHL) и спровођења закона. Примена информационих технологија у војном и цивилном окружењу повећава комплексност у области управљања ризиком. Поред информационе безбедности, војне организације имају задатак да предузму неопходне активности у области сајбер операција, за сврхе одбране и напада. Они зависе од знања и вештина заснованих на технологији и имплементирају их специфичне организације у оквиру војних система. Процена рањивости за циљ има откривање природе рањивости, без разматрања како се оне могу користити за напад, док тестирање отпорности на упаде у систем користи експлоите за упаде у системе и тако процењује врсту и степен ризика који ове рањивости представљају за систем. Међутим, чак и ако представљају две различите активности, са различитим крајњим циљевима, они су комплементарни и међузависни. Пошто је њихова заједничка одлика развој знања и вештина заснованих на истим технологијама, они су од подједнаке важности за управљање ризиком, војне операције у сајбер про-

стору и њихову употребу за одбрамбене и обавештајне активности, као и међународно хуманитарно право.

Кључне речи: тестирање рањивости, процена отпорности на упаде, сајбер напад, Међународно хуманитарно право.

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TENDENCY OF USING CHEMICAL, BIOLOGICAL, RADIOLOGICAL AND NUCLEAR WEAPONS FOR TERRORIST PURPOSES

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Summary:

Chemical, biological, radiological and nuclear (CBRN) terrorism is a serious problem, and its threat and use lead to a new era of terrorism: the epoch much more dangerous than any of the previous periods and the terrorism no one yet knows how to cope with. The disturbing fact is that terrorists can come into possession of weapons of mass destruction. Therefore, the goal of the paper is to analyze the probability of CBRN terrorist actions which have highlighted the growing concerns and increasing signs of convergence between terrorism and CBRN unconventional weapons for terrorist purposes. Terrorism today includes technologies available to anyone and anywhere and deployed through innovative solutions where it is also necessary to understand a complex interaction between the dynamic behavior of terrorist groups and the decisions regarding old and new technologies. The prospect of the use of CBRN terrorism has been confirmed by many countries as an acute security challenge that requires an efficient and quick response and reaction. The paper will also explain the importance of understanding the relationship between terrorist groups and non-conventional weapons, as well as difficulties in identifying factors that may cause the escalation. Since the end of 1990s and since the tragedy of September 11, 2001 in particular, government officials of many countries have pointed out the possibility that terrorist organizations eventually can come into the possession of unconventional materials and develop the possibilities of their use against some countries.

Key words: terrorism, CBRN weapon, unconventional weapons, new technologies, security challenge.

Introduction

Terrorism is a complex social phenomenon, because its causes, nature and objectives as well as the identity of perpetrators vary by epochs or societies. Generally, terrorism is an anti-legal activity that uses or threatens to use violence to instill chronic fear in victims in search of the strategic objectives of terrorists. Terrorist acts are intended to create disorder and insecurity in which reality is perceived as temporary and unstable, especially when the issues of mortality are raised. The use of CBRN weapons for the purpose of warfare has been present for centuries; the use of these weapons for the purposes of terrorism is also very old, but there are significant differences between conventional wars and terrorism. In these circumstances, the biggest challenges for a community are likely to occur if a terrorist act involves the use of CBRN weapons.

Types of terrorism vary depending on the motivation, function, effects, nature of violence and strategies. Terrorists have always been connected, on an amateur basis initially and today they can intend more or less to commit mass attacks with greater number of casualties than it was the case 20 years ago, for example.

The studies of a few cases of earlier CBRN actions have led experts to identify the key characteristics of terrorist groups that could potentially have an interest to use these weapons. It is thought that conservatism is inherent in terrorist organizations, but it must not be forgotten that some terrorists are inclined to innovations in weapons and tactics, as well as to taking risks in actions or in the choice of weapons. Many experts agree that most terrorist organizations want to use proven methods to achieve desired effects. Innovations, especially in the field of CBRN weapons, often indicate terrorists are likely to be led by other factors rather than by pure curiosity and desire to experiment. For some individuals, repression and democratic and strong rule of law are positive determinants of the emergence of CBRN actions which points to a new and more complex global security environment with an increasing risk of terrorists trying to perform a CBRN attack. It is a frightening fact that a single terrorist or isolated terrorist group could improvise a biological weapon or use other ways to spread anthrax, smallpox or other biological agents and thereby cause mass casualties and destroy the health care system of a state.

CBRN weapons are secretly shipped to terrorists or hostile governments and represent a significant and growing threat to many countries. Although the threat of CBRN attacks is widely recognized as the central issue of national security, most analysts assume that the primary danger is a threat of the military use of these weapons in conventional wars with tra-

ditional military means while the threat of covert attacks, which include terrorism, is rashly and unfairly neglected. Covert attacks are difficult to deter or prevent and CBRN weapons suitable for this type of attack are available to a growing number of enemy states and groups. At the same time, restrictions on their use appear to be diminishing, and so-called new terrorists do not always escalate and become apparent only by using unconventional weapons. These weapons are easily spread or transmitted from person to person, have a high mortality rate and a potential impact on public health, causing mass casualties that can crush health systems and cause public panic and social disruption, thus requiring special efforts to suppress them.

When assessing the threat of CBRN weapons, we should take into account the change in capacity to carry out terrorist attacks that are on the rise among countries and non-government elements. Analysts believe that the fear of chemical and biological terrorist attacks is excessive, they point out that, in the past, very few attacks involved these weapons, and even those few attempts that have occurred were mostly thwarted by the authorities. A relative ease with which biological weapons can be obtained, along with other current changes and turbulences in the world, sets the stage for another type of warfare in the 21st century.

The potential for CBRN terrorism has widely grown since 11 September, when some of these materials were used. The danger of terrorist use of nuclear weapons and other weapons of mass destruction represents a very serious threat for many countries; if a terrorist group could gain access to this weapon, it is highly likely it would use it, or threaten to use it. Although there is very little information on terrorists and their ability to come into possession of nuclear weapons or on their intentions to get them, the risk of CBRN weapons has certainly increased since the terrorists started to become more familiar with these agents and their harmful consequences.

Discovering the nature of the threat of biological weapons, as well as the appropriate response to them requires an emphasis on the biological characteristics of these instruments of war and terror. Preparing for a terrorist attack may seem daunting and there are a small number of people with practical experience and a good knowledge of CBRN weapons, because until recently there was no need to own them. In the past, most of the planning regarding emergency response to terrorism concentrated on the concerns of open attacks (bombing). However, the threats of CBRN weapons are taken seriously, especially in the USA, where media, fascinated by new weapons of mass destruction, encourage a growing fear for public safety. Terrorists who have significant human and material resources are much more likely to realize their intentions than lone perpetrators or small

terrorist groups. A CBRN terrorism threat is certainly a matter of concern; however, terrorists will face many obstacles in the implementation of an attack of this kind. This includes the acquisition of materials and preparation for spreading them as well as a selection and a survey of a chosen objective and a correct dose required to achieve a desired effect.

The growing threat of CBRN terrorism

Terrorism can be defined as a deliberate act of violence intended to cause damage, but also to create an appropriate political and ideological situation, so that the use of these non-traditional weapons of terror outside the context is obvious, and the goals will not be military, but civilian ones (Bioterrorism, chemical weapons, and radiation terrorism, nd). Toxic substances, regardless of whether they are of animal, vegetable or mineral origin, were used throughout the history for political assassinations and sabotage; despite the risk of severe penalties, the prospects for success favoured the use of toxic substances. Such use has always been reduced, however, since only a small number of people had access to substances and possessed the ability of learn how to use them (Pascal, 1999).

CBRN weapons are rightly viewed with a special sense of horror, their effects can be devastating and indiscriminating, and they take the most stringent toll among the most vulnerable population, non-combatants (e.g. a biological attack cannot be detected sufficiently fast after the disease spreads through the population). Moreover, chemical and biological weapons are a particularly attractive alternative for groups that do not have the ability to produce nuclear weapons, and this risk raises complex but important ethical issues (London, 2003). The common name for CBRN terrorism which causes the death of a large number of people, large scale damage and a strong echo worldwide is post-industrial or hyper-terrorism. This means that non-state elements possess and dispose of assets that were previously held only by states, but unlike them, which often fear reprisals after WMD attacks, terrorists, having no geographical location, are ready to use WMD with much less scrupulousness and fear (Kurmnik, Ribnikar, 2003). Some authors have described the factors that make chemical, biological, radiological and nuclear terrorist attacks in many ways unique and demanding, such as an element of surprise, invisible agents, ordnance, the risk of repetition and new types of risks (Ruggiero, Voss, 2015).

In the past 30 years, the use of CBRN weapons has become a major concern for many nations around the world. The public has become insensitive to traditional terrorist attacks that seem to be a less efficient way for

terrorist organizations to achieve their goals. What causes shock and fear is actually presenting the properties of weapons which can be used by terrorist organizations to enhance their efforts and the effectiveness of attacks. CBRN terrorism is often a synonym for weapons of mass destruction, although this form of terrorism and related incidents do not require attacks and inflicting harm to large numbers of people - they do not even require deadly attacks at all. The number of studies on this type of terrorism is limited due to the lack of available data on this terrorism type. There is a very small number of databases of CBRN incidents, and even the existing ones have relatively little to do with them and they are compared to conventional terrorism (Jesse, 2012).

Some experts emphasize the factors that promote such attacks and these factors include the availability of information and expertise, increased frustration of terrorists, demonization of the target population, as well as a millennial, apocalyptic or messianic vision. Experts also differ in opinion when it comes to possible perpetrators of CBRN incidents, and include religious fundamentalists and cults[1] as possible perpetrators of such attacks, especially when these groups address to ethereal audience, emphasizing the hatred of unbelievers (Ivanova, Sandler, 2007).

Concerns about super terrorism which involves the use of CBRN weapons are mainly focused on what terrorists can do in the context of our social reality, with an emphasis on terrorist motivations, initiatives and limitations. When considering which terrorist groups may be inclined to commit CBRN terrorism, it is important to recognize the spectrum of these acts, as well as to analyze the following categorization: (a) massive casualty events produced by conventional weapons; (b) CBRN scams; (c) conventional attack on a nuclear facility; (d) limited-scale chemical or biological attack or a radiological dispersion; (e) large scale chemical or biological attack or a radiological dispersion; and (f) CBRN strikes (super terrorism) that can lead to thousands of victims. In addition to the motivation and willingness to inflict mass casualties in any way, terrorists must have technical and financial capabilities to come into possession of material and acquire skills for these types of weapons and materials and carry out a successful attack. Chemical and biological weapons can pose a risk to terrorists thus deterring them from using such weapons (Post, 2005, pp.148-151).

[1] The question of whether there is a new trend towards massive casualty attacks remains at least partially opened as well as the link between religious terrorism and willingness to kill indiscriminately and even use weapons of mass destruction,, which is so evident in discussions of new terrorism. Therefore, it should be noted that the historical evidence does not support the idea that there are greater chances that religious groups use chemical or biological agents (Tucker, 2001, pp.1-14).

The possibility that terrorists use chemical or biological substances may increase over the next decade, according to US intelligence agencies. According to CIA[2], an interest among non-state actors, including terrorists, for biological and chemical materials is real and growing, and the number of potential perpetrators is increasing. The agency also noted that many of these groups had developed an international network and did not need to rely on state sponsors for financial and technical support. However, it is believed that it is less likely that terrorists would choose chemical and biological weapons over conventional explosives, because these weapons are difficult to control and their results are unpredictable (Condesman, Burke, 2001).

The risk of CBRN weapons is growing since terrorists are better acquainted with these agents and their potential for causing harm[3]. These agents possess desirable characteristics as weapons of terror; they are biologically invisible to the naked eye, odorless and potentially lethal in the form of particles; natural organisms are so readily available, and can be "camouflaged" in natural disasters and used to spread fear and various diseases. Chemical agents quickly attack the critical physiological centers of the body, disabling or killing the victim. Biological and chemical weapons require the application of huge amounts of resources and result in different effects, causing fear and panic in the contaminated areas. Often referred to as "weapons of mass destruction", but, in medical terms, they are weapons of potential mass casualties because they can lead to massive death toll in the absence of preventive measures and timely response (Meyer, Spinella, 2014, pp.645-656). "Bioterrorism is the intentional use of microorganisms or toxins derived from living organisms used for hostile purposes intended to cause disease or death in man, animals and plants, on which they depend". The threat of bioterrorist attacks is real, and each individual is a potential terrorist, when terrorists are "invisible" prior to an attack which also can be "invisible" in the form of causing infectious disea-

[2] In 1999, a biparty commission led by former CIA director John Deutch released its report on the readiness of the US to deal with weapons of mass destruction. While the commission expressed concerns about the armament of Russians with nuclear explosives and about Chinese exports of missile materials, it was also upset by terrorist storage of biological weapons. The worst nightmare of the Commission was a possibility of anthrax attacks which can send a huge number of people into hospitals. Just because terrorists have not shown much interest and success with biological weapons in the past, does not mean they will not use them in the future. Reports indicate, with different levels of reliability, that Osama Bin Laden, Islamist Jihad and the Kurdish PKK have shown interest in biological weapons in recent years. "These events did not escalate, but they certainly could have" (Carus, 1999).

[3] For example, ten kilograms of anthrax are as deadly as nuclear explosive of 10 kilograms, but they are cheaper and easier to buy and carry (Gompert, 2000 pp.22-23.).

ses or epidemics. Citizens who are not aware they are infected are potential safety hazard and so-called dangerous bodies (Mijalković, 2011).

In the last ten years, the issue of CBRN weapons has attracted the attention of experts, but a list of priorities by the heads of states has never been established. Biological weapons almost became forgotten after they had been banned by the 1972 Convention on Biological Weapons. A significant attention was paid to them during the 90s of the last century. The important thing is that biological weapons attract much less attention than other similar weapons, but probably represent the greatest danger, and in addition to their use in war, they are available as instruments of terror in peace. Some countries showed willingness to use such weapons against defenseless populations to achieve strategic objectives, and in this regard, some analysts believe that those who attacked the World Trade Center in 1993 applied cyanide on their bombs (this was not confirmed, but a large amount of cyanide was found in possession of the perpetrators). Such a group will prove to be less inefficient, because if terrorists decide to shock and surprise the government by inflicting enormous damage, CBRN weapons will become more attractive and more accessible (Bettis, 1998).

Motives and forms of behavior of individuals and groups who acquired or used CBRN weapons have existed since long ago and there is no doubt that modern society is vulnerable to such attacks (Tucker, 2000). Fear of biological terrorism is certainly greater than the fear of the conventional forms of terrorism; some of these fears are justified and some are often exaggerated. Some agents are really very contagious and deadly, and if used properly, have a potential to result in casualties similar to those in a nuclear attack. Perhaps the scariest aspect of biological weapons is that the body is attacked without warning, people are afraid of the threat as it is invisible, and cannot be heard or felt. The history of warfare, terrorism and crime involving biological agents in the last century is considerably less dangerous and more deadly than the history of conventional warfare (Parachini, 2001). Today, some states and some terrorist groups can more easily overcome technological barriers due to the increased flow of information and access to previously unavailable technologies. Along with nuclear and chemical weapons, biological weapons are part of an unholy trinity of weapons of mass destruction (Davis, Johnson-Winegar, 2000, pp.15-28).

The society is now faced with the threat of an apocalyptic and asymmetric war scenario in which kamikaze attackers are able to arm

themselves with WMD[4] without even having to have a "physical" weapon to create fear; they probably still prefer simple, proven methods: a stampede in an enclosed place, or just an explosive device, which will kill many people[5] (Palmer, 2004, pp.3-9). Early detection and response to biological or chemical terrorism are crucial to solving this problem (U.S. Congress House, 2003, p.117).

Potential devastating effects of CBRN terrorist attacks

Unlike nuclear terrorism, which remains problematic and complex to implement and is still largely theoretical, chemical terrorism is concrete and practical, and in several cases has already been used. In biological terrorism, attacks are not direct and immediate, they become apparent only after a few hours or days (after some victims leave the scene of the attack) when it may be more difficult to detect the perpetrator and the motive of the attack (Ganor, 1998). The act of biological or chemical terrorism can range from aerosol anthrax[6] to contamination of food products. It is important to predict when and how such an attack may or may not occur. Preparing the nation to confront this threat poses a major challenge, but it should be noted that the unpreparedness can have devastating effects (U.S. Department of Health and Human Services, 2000). Biological terrorism offers a possibility of a reattack, which adversely affects the confidence and constantly asks for investing resources to achieve a specific model of defense. If an attack is repeated, and the state is not sufficiently prepared, then the corrosive psychological and political consequences of the attack will be even bigger, because people will want to know why more has not be done on this issue (Danzing, 2003).

[4] From 1975 to the mid-2000s, there were only 126 chemical and biological attacks around the world.

[5] Unlike the attacks on New York and Washington, a biological attack would not be accompanied by explosions and police sirens; instead, terrorists could unleash a deadly biological weapon in a crowded mall or a metro station, which poses a danger to millions of people (US Congress Senate 2001, p.255).

[6] The World Health Organization estimates that, 3 days after releasing 50 kg pores of bacteria within 2km in a city of 500,000 inhabitants, favorable winds could lead to infection of even 125,000 people, producing 95,000 deaths and this number is much more deadly than in any other scenario of the release of this agent (Cieslak, Eitzen, 1999, pp.552-555). An anthrax bacterium that causes deadly disease is common in cattle and sheep but the real danger is actually its potential to be used in a terrorist attack, because it is odorless and tasteless, invisible and not immediately visible in the attack; only a few hours later, people who ingest the bacteria start to experience symptoms of choking. Later, medical help would be of no use (Foer, 1998).

There is a common misperception that carrying out a biological terrorist attack is easy; in fact, any wrong step in the preparatory phase (a strain must be cultivated under aerobic or anaerobic conditions, it should be purified in order to give the best results) can make an attack[7] fail. There are also possibilities for a series of missteps during the spreading, due to ignorance and improper dosage; it is necessary to obtain the desired effect, to analyze the ventilation system in a building - or wind speed and direction if an open attack is planned - and misconceptions regarding the path of agents entering the body (Lowe, Carus, 2016).

Chemical and biological weapons vary in effects and ease or difficulty in production and applications; from a philosophical perspective, these weapons have been with us for millennia. However, the industrial age resulted in a mass production and expansion of these weapons, together with the development of a number of stronger agents as compared to those that already occur in nature (Kopp, 2008). The use of chemicals as weapons of mass destruction poses a real threat, as well as a clear and present danger to Western societies. The 1995 gas attack in Tokyo proves that these chemicals can be delivered in a way that requires little sophistication, which makes it very attractive to terrorists (Rivera, 2013).[8] On the surface, it seems that both Reineesh and Aum Shinrikio[9] cults resorted to chemical and biological terrorism to prevent attempts of law enforcement to interfere in their activities; however, the deeper motivations and intentions were fundamentally different, which contributed to significant deviations in their preparations for CBRN terrorism and the agent selection. Such differences are significant in the assessment and review of risks and consequences (Zenders, et. al, 2006).

Chemical, biological and toxicological weapons can produce mass casualties if they are effectively spread, but they produce different effects. Chemical weapons, mainly composed of synthetic chemicals, need the largest amounts of material to be effective and cause the effects lasting from a couple of minutes to several hours. These weapons are actually

[7] One reason why there were so few successful attacks of chemical or biological terrorism is because a successful attack requires overcoming a series of major technical obstacles: accessing specialized chemical substances or infectious types of microbes, procurement of equipment and know-how for the production of agents and their dissemination; developing an organizational structure that is able to resist infiltration or early detection of law enforcement.

[8] This cult initiated at least nine biological attacks in the early 1990s, using anthrax spores or germs that cause botulism, but all these attempts failed. In addition, laboratory cultures of viruses and bacteria are often kept in ideal conditions, but may not be so strong in the real world (Hall, 1998, p.92).

[9] The above-mentioned attack on the subway in Tokyo was designed to prevent a police raid on their premises. A year earlier, the same group carried out a less-known sarin attack in Matsumoto, which led to 7 deaths and 600 wounded; the attack was directed against the judges representing the government in a dispute with the cult over land.

chemical compounds that are harmful to the human body, even when entered in small doses, and the effects may occur very soon after exposure, from several minutes to several hours. Biological weapons are made of natural pathogens that require a minimum of material to be effective, but generally have an incubation period of several days before they cause symptoms. As a result, these weapons require much less material than usual chemicals and they need more time to produce effects; diseases caused are primarily debilitating, such as K fever or smallpox which may be fatal. Infectious pathogens such as smallpox[10] have the potential to extend the effects of the attack among victims, and the symptoms will require a lot of time to develop, so a covert biological attack may be recognized only after several days (Shea, 2004).

Chemical weapons (first used in World War I) can include any of a number of different substances, each of which has its own application, but they all can cause enormous suffering and death. Chemical weapons were first used in World War II. The agent known as "gas" (actually a vapor or aerosol of toxic substances) consisted of commercial chemicals used to kill pests. In addition, the aforementioned chemicals have terrible consequences, causing long-lasting pain and usually agonizing death, which is why they are often used by terrorists and fanatics (Baker, 2006). Also, the modalities used to commit terrorist attacks in Oklahoma City, Japan, Madrid and New York, range from conventional high explosives to chemical and biological weapons, all of which were used in the recent past. High-order explosive (HE) was the first available explosive after Alfred Nobel invented dynamite in 1866, and, since then, several others have been developed and used in up to 66% of terrorist attacks (Hamele, Bradley Poss, Sweney, 2014, pp.15-23).

One should be aware of potential bioterrorist acts - their probability is completely unknown, and an attack might even never happen. However, we have seen that terrorism can occur as one of the most painful problems of the post-cold war period and that the terrorists are always on a lookout for new weapons (Shallala, 1999, pp.492-494). Hazardous biological agents can be distributed through air, food, water, or insects, their effects can be seen after a few days, during which the infectious disease can spread to others who were not initially exposed. Some biological agents such as anthrax and plague produce symptoms that are easily confused with the flu or other less infectious diseases, leading to delays in diagnosis and identification (Report to Congressional, 2003, pp.117).

[10] This virus, which is among the most dangerous organisms that could be used for bioterrorism, is not widely available and the international trade on the black market in weapons of mass destruction is the only way to gain access to its possession (O'Toole, 1999, pp.540-546).

Nuclear and radiological materials as weapons of mass destruction

The possibility that terrorists use weapons of mass destruction has become undeniable and probably because of that interest for terrorism appeared also in the natural sciences. *Scientific American*, a general scientific journal, published an article entitled "Thwarting nuclear terrorism", whose subtitle states that "many reactors studied have a high degree of enriched uranium that terrorists could use to build nuclear bombs." This can be seen as a means of proving the growing willingness to treat terrorism as an expansive pandemic that threatens the very existence of human civilization (Wolf, Frankel, 2007, pp.259-279). Nuclear material is more difficult to obtain than biological or chemical precursors, but it is more and more accessible due to the deterioration of the situation in the countries of the former USSR (Elland, 1998, pp.26-40).

The nuclear terrorist attack is an event in which a terrorist organization uses a nuclear bomb to cause mass murder and destruction. This form of terrorism also includes the use or threat of use of weapons based on the fission of radioactive materials as well as attacks on nuclear power plants in order to produce enormous and irreparable damage to the environment. In the latter case, a terrorist organization does not need to develop, possess or take control of a nuclear bomb that would cause great harm. It just needs to use a conventional weapon against one of many nuclear reactors in the world, seriously damaging it and releasing radioactive substances into the atmosphere in such a way to endanger a large number of people. Terrorists can buy or come into possession of nuclear weapons from any country, especially from a country that supports terrorism, because many "revolutionary" states of the "Third World", such as Iran, Iraq and Libya[11] actively and regularly assist various terrorist organizations (Ganor, 1998).

The question is why terrorists would, despite all the accompanying difficulties and obstacles, decide to use weapons of mass destruction? Attracting attention is certainly one of the primary reasons because released toxic particles, including radioactive ones, cause much greater amount of fear than their real destructive power. This fact is especially attractive to those terrorist groups who feel that no one takes them seriously any more,

[11] Consent to bomb *El Shifa* was given by fewer than ten highest officials of the United States, who supported the charges that this city produced chemicals for weapons and not just stored or reloaded them. However, Clinton's advisers claimed they had no new evidence to support the conclusion that the mentioned factory was linked to Bin Laden and the development of Iraq's chemical weapons program (Whitelaw, et al, 1999).

because the government or the public eventually become insensitive to their stories and requirements (Stern, 2004).

The possibility of devastating attacks, including possibly weapons of mass destruction is very real and we should not neglect the fact that Al Qaeda has aggressively sought nuclear materials from its earliest days and biological weapons since the late 1990s, which could have far-reaching consequences and implications for the security of individual states, where the basic living conditions would be violated and the trust in the American political system undermined (Benjamin, 2008).

Nuclear detonation by terrorists would probably lead to massive casualties. In contrast, a radiological attack is likely to be less violent, but could significantly contaminate the urban environment, causing economic and social collapse and both types of attacks could have significant psychological impact on the human population. Thorough analyses from previous years have concluded that it is a difficult task for terrorists to construct weapons of mass destruction, but regardless of this, terrorist organizations may over time develop such a possibility, if they get enough fissile material, perhaps through theft (O'Neill, 1997). Two options for the construction of nuclear devices by terrorists are: to use the earliest design principles, the so-called rough design that uses more advanced principles in the framework of the so-called sophisticated design. A rough design is discussed primarily in the context of the problems faced by terrorist groups. Schematic fission explosive materials from the oldest to the most modern types show, in a qualitative way, the principles that are used to achieve the first fission explosions are widely available; however, detailed drawings and specifications that are essential before it is possible to plan the development of specific parts are not available (Mark, et al, 1987).

Terrorists are trying in every way to come into possession of weapons of mass destruction, which is one of the most serious threats to the human race and the means of attack may include a range of systems, from highly sophisticated weapons such as atomic bombs to underdeveloped improvised radiological devices. Although high explosives are not traditionally recognized as WMD weapons, high yields of some low-yield explosives caused significant devastating consequences for both people and their surroundings (Terrorism and WMD, 2007). The concept of nuclear terrorism is probably the least understood of all other hazards arising from nuclear weapons, simply because it is known that terrorist groups are developing and coming into possession of nuclear weapons. Therefore, the seriousness of these threats remains questionable; conventional notions indicate that nuclear terrorism is too hard to undertake because it would require considerable effort, expertise and competence of perpetrators (Schwartz, 2013).

Conclusion

The international community is trying to identify a set of early warning signs and the most important indicators of possible future activities of terrorists who acquire and use unconventional CBRN weapons as a means of achieving their goals. Many believe that it is only a matter of time when another CBRN terrorist attack will occur, where the form, time and place of the attack are unpredictable. There is a relatively small set of data in the formulation of general observations about the terrorists' potential of using unconventional weapons; in addition, details on many of these cases are incomplete and often ambiguous, which only further complicates the task of accurately and credibly describing the scope and size of the risk. The use of CBRN weapons can transform the way countries wage wars, and if used on a large scale against civilians, it could redraw the patterns of society because people are becoming more concerned about the casualties of this silent and deadly type of war. We see that terrorists continually search for new weapons, and scientists predict that in the next few decades, these weapons will pose an enormous challenge. As with the emergence of infectious diseases, early detection and control of biological or chemical attack depend on a strong and flexible public health system at the local, state and federal level. The first challenge for the population is to be aware that the act of bioterrorism might happen and its probability is completely unknown and uncertain; the attack may never happen, but the fear is certainly present. However, it has been proved that terrorism can occur as one of the most painful problems of the post-cold war era. In the event of a biological or chemical attack, there is no effective radar or a device that can it identify in time - it is this unpredictability that equally concerns government officials and ordinary citizens alike. CBRN weapons are weapons of terror and therefore their attractiveness, efficiency and psychological effects have reflected on individuals, groups and social levels. Health infrastructures and the public must be prepared to prevent diseases and injuries that could occur due to biological and chemical terrorism, especially during covert terrorist attacks.

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ТЕНДЕНЦИЯ ПРИМЕНЕНИЯ РАДИАЦИОННОГО, ХИМИЧЕСКОГО И БИОЛОГИЧЕСКОГО ОРУЖИЯ В ТЕРРОРИСТИЧЕСКИХ ЦЕЛЯХ

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ОБЛАСТЬ: РХБ оружие и защита
ВИД СТАТЬИ: обзорная статья
ЯЗЫК СТАТЬИ: английский

Резюме:

Радиационный, химический и биологический терроризм (РХБО) сегодня представляет огромную проблему, а масштабы его угрозы, ввиду использования такого рода оружия создали новую эпоху терроризма, которая опаснее всех предыдущих, ибо с таким терроризмом пока неизвестно как бороться. Пугает факт того, что террористы могут найти доступ к оружию массового поражения. Учитывая такое положение автор настоящей статьи провел анализ вероятности терактов с применением РХБО. Современный терроризм использует инструменты инновационных технологий, которые могут

быть доступны каждому человеку в любой момент и в любом месте. Поэтому необходимо понимать каким образом изменилась поведенческая динамика террористических групп в эпоху новых технологий. Перспективы применения РХБО в террористических целях подтверждена многими странами, как острейшая угроза безопасности общества, требующая быстрых и эффективных решений и реакции.

В данной работе подчеркивается насколько важно понимать роль неконвенционального оружия в руках террористических группировок, а также насколько сложно идентифицировать факторы, вызывающие эскалацию террористическх действий. Данный вопрос стал особенно актуален после трагедии 11 сентября 2001 года, хотя представители власти многих стран несколько лет до этого выражали беспокойство на счет того, что неконвенциональное оружие может быть использовано террористическими структурами и направлено против отдельных государств.

Ключевые слова: терроризм, РХБ оружие, неконвенциональное оружие, новые технологии, вызов безопасности.

ТЕНДЕНЦИЈА УПОТРЕБЕ ХЕМИЈСКОГ, БИОЛОШКОГ, РАДИОЛОШКОГ И НУКЛЕАРНОГ ОРУЖЈА У ТЕРОРИСТИЧКЕ СВРХЕ

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ОБЛАСТ: НХБ оружје и заштита
ВРСТА ЧЛАНКА: прегледни чланак
ЈЕЗИК ЧЛАНКА: енглески

Сажетак:

Хемијски, биолошки, радиолошки и нуклеарни тероризам (CBRN) данас је озбиљан проблем, а његова претња и коришћење представља увод у нову епоху тероризма – епоху много опаснију од било ког претходног периода и тероризма са којим нико још не зна како да се носи. Узнемирујућа је чињеница да терористи могу да дођу у посед оружја за масовно уништење, а циљ рада је анализа вероватноће CBRN терористичких акција где је истакнута све већа забринутост и све већи знаци конвергенције између тероризма и неконвенционалних CBRN оружја у терористичке сврхе. Тероризам данас укључује технологије доступне свакоме, било где и када, распоређене кроз иновативна решења, где је неопходно такође разумети комплексну интеракцију између динамике понашања терористичких група и одлука у вези са старим и новим техноло-

Krstić, M., Tendency of using chemical, biological, radiological and nuclear weapons for terrorist purposes, pp. 481-498

гијама. Перспективу употребе CBRN тероризма потврдиле су многе државе као акутни безбедносни изазов који изискује ефикасан и брз одговор и реакцију. У раду ће, такође, бити расветљен однос између терористичких група и неконвенционалних оружја, као и тешкоће у идентификацији фактора који могу изазвати његову ескалацију. Након трагедије 11. септембра 2001. године, али и неколико година пре, званичници многих држава истакли су могућност да терористичке организације временом дођу у посед неконвенционалних оружја и развију могућности њихове употребе против појединих држава.

Кључне речи: тероризам, хемијско оружје, биолошко оружје, радиолошко оружје, нуклеарно оружје, неконвенционална оружја, нове технологије, безбедносни изазов.

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СТРУЧНИ ЧЛАНЦИ
ПРОФЕССИОНАЛЬНЫЕ СТАТЬИ
PROFESSIONAL PAPERS

IMPROVED PERFORMANCES OF THE WIND INLET OF THE SAVONIUS ROTOR

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Summary:

In this study we analyzed the design changes through increasing vertical angles of the top and bottom plates of the wind inlet of a Savonius rotor, in order to obtain better results and better system performances. A designed wind inlet is placed in the front part of the rotor in order to prevent negative torque opposing rotor rotation. The geometric parameters of the wind inlet are determined to obtain optimal performances. Analyses and tests have shown that the increase of the vertical angles of the top and bottom plates on the wind inlet of a Savonius rotor leads to better rotor performances in comparison to the use of a classic wind inlet. It was found that the best results are achieved with increasing vertical angles of the top and bottom plates of the Savonius rotor wind inlet for a total of 15°, where the rotor speed is 395 revolutions per minute.

Keywords: vertical angles, wind, Savonius rotor, rotors, plates, wind inlet.

Introduction

The need for energy increases with the increase in population and higher energy consumption consequently increases the price of fossil fuels. At the same time, due to higher consumption of fossil fuels, there is a problem with global climate change caused by increased emissions of carbon dioxide released during the combustion of fossil fuels. Using renewable

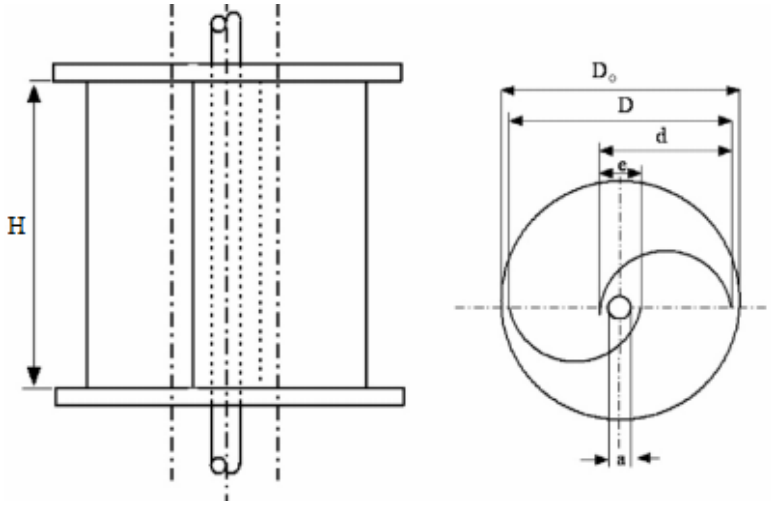
energy is an important goal of energy policy in the world (Frederikus, et al., 2015, p.298). Wind is an ecological source of energy that has huge potential to meet the energy needs of people as well as to mitigate climate change due to greenhouse gas emissions from fossil fuels (Frederikus, et al., 2015, p.298). This is why wind energy is an important resource of clean energy (Mahmoud, et al., 2012, p.19), which has received considerable attention in the last decade. It is estimated that there is about 10 million MW of wind energy available on Earth (Frederikus, et al., 2015, p.298). Wind energy is very useful as a clean energy source and wind turbines are the most important source of wind energy (Burçin, Mehmet, 2008b, p.3425). Wind power may to some extent contribute to energy production and many countries can use it through windmills. Global industry of windmill-produced energy, which dominates in Europe, North America and Asia, increased by about 29% in 2008 and exceeded 120 GW (Terje, Susanne, 2014, p.197). Wind generators are used for converting wind energy into mechanical energy and for electricity production. There are different types of wind turbines with a vertical axis of rotation such as the Savonius rotor, Darius rotor, or H-Darius rotor. The examples of such windmills can be seen in Figure 1 (Frederikus, et al., 2015, p.298).

a) b) c)

Figure 1 – The windmill with a vertical axis of rotation of
a) Savonius rotor, b) Darius rotor, c) H-Darius rotor
Рис. 1 – Ветродвигатель с вертикальной осью вращения
a) ротор Савониуса b) ротор Дариуса, c) ротор Х-Дариуса
Слика 1 – Ветрењача са вертикалном осом ротације
a) Савониусов ротор, b) Дариусов ротор, c) Х-Дариусов ротор

Savonius rotor

A Savonius rotor is a wind rotor with a vertical axis invented by Finnish engineer Sigurd Savonius in 1925 (Burçin, Mehmet, 2008b, p.3425). Although these rotors have lower performances than usual wind rotors with vertical axis, they still have some advantages over others: they start to work on their own independently of the wind direction, they have a high starting torque at lower wind speeds, and a simpler and cheaper structure (Burçin, Mehmet, 2010, p.821). This motor has a simple design. It has good initial characteristics and functions at relatively low wind speeds. It is not necessary to direct such windmills, because they can work in all wind directions (Dobrev, Fawaz, 2011, p.712). However, a Savonius rotor has low aerodynamic efficiency. It is constructed of only two vertical half-cylinders, as shown in Figure 2. The performance of Savonius rotors is significantly affected by the ratio of the rotor height (H) and the rotor diameter (D). In addition, the performance of the engine is influenced by overlap (β) that can be expressed as $\beta=(e-a)/d$, where *e* is the interspace, *a* is the shaft diameter and *d* is the blade diameter. Savonius rotor performances have been studied by many researchers from 1977 to 2010, to determine the optimal design parameters of the rotor (Mahmoud, et al., 2012, p.19).



a) b)

Figure 2 – Scheme of the single Savonius rotor: (a) a side view; (b) top view
Рис. 2 – Схема ротора Савониуса: (a) вид сбоку; (b) вид сверху
Слика 2 – Шема јединственог Савониусовог ротора:
(a) поглед са стране; (b) поглед одозго

The efficiency of the Savonius rotor is, however, lower than that of other wind turbines. The reason for its low efficiency is mainly that, at the time of one rotation, one rotor blade moves against the wind while the other moves in the direction of the wind. However, with the advantages of its simple design and low cost of construction, the Savonius rotor is mainly used for water pumping and ventilation on a small scale (Kunio, Jitendro, 2007, p.580).

The Savonius rotor performance power ($C_P \approx 15\%$) is rather low compared to those windmills with a horizontal axis ($C_P \approx 45\%$) and to Darius-type windmills with a vertical axis ($C_P \approx 35\%$) (Burçin, et al., 2008a, p.1673).

In the literature, there are available various studies conducted in order to increase the performance of Savonius rotors. A lot of theoretical and experimental research has been done with the aim of improving the aero-dynamic performances of the Savonius rotor (Burçin, Mehmet, 2010, p.821). In these studies, many scientists have experimentally and numerically examined the effects of various Savonius rotor design parameters, such as the ratio of the rotor dimensions, overlapping and the space between the rotor blades, the profile of the blade cross section, the number of blades, and the presence or absence of the end plates of the rotor. Many experimental and numerical studies have been conducted on the Savonius rotor to investigate the velocity field and the pressure on the blades. There are also some other studies for the design and development of small Savonius rotors for the local production of electricity (Burçin, et al., 2008a, p.1673).

A conventional Savonius rotor is provided with blades made of two half-cylinders in rotation about the vertical axis, with or without interspaces (Burçin, et al., 2008a, p.1674). The Savonius rotor is classified as a vertical axis turbine whose working principle is mainly based on the difference in resistance between the convex and concave parts of the blades (Dobrev, Fawaz, 2011, p.712). Wind power exert pressure to both the convex blade and the concave blade as shown in Figure 3.

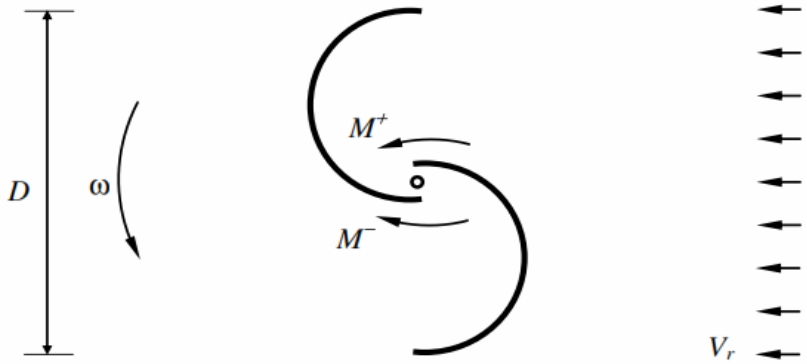


Figure 3 – The direction of torque affecting the rotor blades using wind power

Рис. 3 – Направление крутящего момента, воздействующего на лопасти ротора с помощью ветра

Слика 3 – Смер обртне силе који утиче на лопатице ротора помоћу снаге ветра

Since the force generated on the convex blade of the Savonius rotor is smaller than the one on the concave blade, the rotor rotates in the direction of a positive force. However, it is important to prevent the negative torque opposing the rotor rotation in order to increase the rotor power. So, in order to prevent the negative torque on the convex blade, a wind inlet in front of the Savonius rotor was designed to increase the low performance of the rotor (Burçin, et al., 2008a, p.1674).

Experimental study of the Savonius rotor with the wind inlet and a new design

In this paper, an experimental study was carried out and the following geometric parameters of the Savonius rotor were taken into account:

The rotor diameter (D) and the rotor height (H) are 32 cm and, in accordance with the optimal ratio of *e/d*=0.15, the interspace (*e*) is 2.6 cm. The thickness of the blades is 2 mm. Two end plates are made of 4 mm thick steel plates with a plate diameter (D_0) of 35.2 cm. The Savonius rotor shaft is attached at the top and the bottom with ball bearings to reduce friction forces to a minimum. The rotor is attached to the experimental setting with ties to facilitate assembly and disassembly (Burçin, et al., 2008a, p.1674).

The Savonius rotor with the wind inlet was designed to improve the low aerodynamic performances of the Savonius rotor. This design is both

simple and inexpensive, and consists of flat plate sheets. This wind inlet is used to turn the wind impinging on the front of the rotor and guide it to the rotor (Burçin, Mehmet, 2010, p.822). The aim of this study was to make and then analyze changes in the angles of the upper and lower plates of the wind inlet without changing the basic structure of the Savonius rotor to improve performances and increase the efficiency of the rotor. In this study, a wind inlet is used to direct wind and it is of simple construction (Burçin, et al., 2008a, p.1673).

The wind inlet with its geometric parameters is illustrated in Figure 4. The parts of the wind inlet (a and b curtains) are plates that deflect the wind as shown in Figures 4 and 5. The construction of these rejection panels is simple and cheap, because they are made from flat sheet plates (Burçin, et al., 2008a, p.1674).

A series of experiments was performed with and without curtains to test the performances. The experiments for the wind inlet angles were conducted with values α = 45° and β = 15°, and the length of the curtains was l_1=45 cm, l_2= 52 cm, as the best results (Burçin, et al., 2008a, pp.1675-1676).

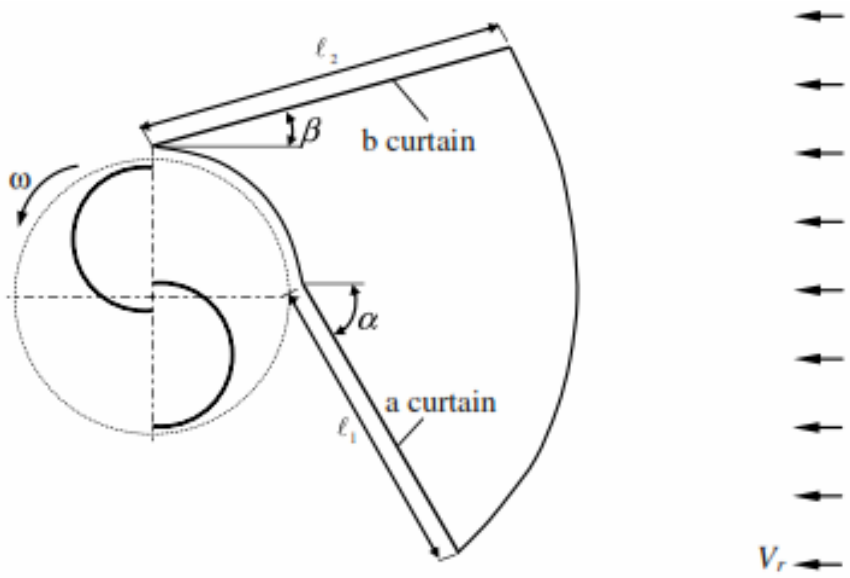


Figure 4 – Geometric parameters of the wind inlet
Рис. 4 – Геометрические параметры конфузора
Слика 4 – Геометријски параметри уводника за ветар

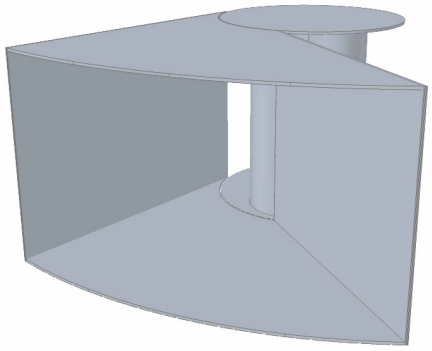


Figure 5 – Savonius rotor with the wind inlet, where the vertical angle of the upper and the lower plate is zero degrees
Рис. 5 – Ротор Савониуса с конфузором, вертикальный угол верхней и нижней стенки которого составляет 0°
Слика 5 – Савониусов ротор са уводником за ветар, где је вертикални угао горње и доње плоче нула степени

Experimental setting and other equipment

The experimental setting consists of a wind generator, a Savonius rotor, a wind inlet and measuring devices for measuring wind speed and number of revolutions. The wind generator (a fan) used in the experiments has a power of 1.5 kW and an outlet cross section diameter of ϕ = 50 cm. Wind speed can be changed using a built-in potentiometer on the fan motor whose revolution number control regulates the wind speed. The Savonius rotor, the wind inlet and the gauges are set away from the fan. The Savonius rotor and the wind inlet with the curtains are placed on a steel table. The Savonius rotor is connected at the upper and lower part with the steel structure by ball bearings to reduce friction force. The designed wind inlet is placed in front of the Savonius rotor. Wind speed and the number of revolutions are measured with a multifunction anemometer and a tachometer (tachometer). The MASTECH MS6250 anemometer with a measuring range from 0.4 to 30 m/s was used to measure wind speed and the accuracy of the multifunctional anemometer is ± 0.2 m / s. Angular velocity is measured by the PCE DT-62 optical tachometer with a measuring range from +2 to +99,999 rpm with a precision of ± 0.05% +1.

The Savonius rotor with the wind inlet is set at approximately 830 cm from the fan outlet cross section. The rotor with the wind inlet was installed in the same position for each measurement. The rotor with the wind inlet

acts under the same wind speed conditions in order to compare the different angles of the upper and lower plate of the wind inlet.

The experiments were carried out at an average wind speed of 7 m/s (*Re*=1.5x10^5) (Burçin, et al., 2008a, p.1675).

This speed of 7 m/s was measured at a measuring grid attached at about 170 cm from the center of the Savonius rotor with the wind inlet.

Experimental results

A series of experiments was carried out with a gradual increase of the vertical angle of the upper and lower plate of the wind inlet of the Savonius rotor in order to determine the optimal angle which would improve the system performance. The angles of the lower and upper plate were equally increased and the angles of 15^o, 30^o, 60^o, 90^o and 120^o were tested. The total increase of the wind inlet upper and lower plate angles was marked with γ, the angle of the wind inlet upper plate was marked with γ/2 and the angle of the wind inlet bottom plate with γ/2. The angle of 0^o was first tested, which means that there is no increase in vertical angles of the wind inlet top and bottom plates. Then, the next testing was done with an angle of 15^o, which means that the angle of the upper plate increased by 7.5^o and the angle of the bottom plate for 7.5^o giving a total of 15^o. In this way, the test was conducted with other angles. Increasing the vertical angles of the upper and lower plates of the wind inlet of the Savonius rotor can be seen in Figure 6.

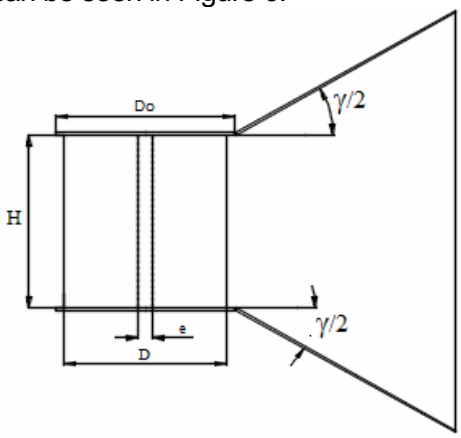


Figure 6 – Vertical change of the upper and lower angles of the wind inlet
Рис. 6 – Вертикальное изменение угла верхней и нижней стенки конфузора для ветрового потока
Слика 6 – Вертикално померање угла горње и доње плоче уводника за ветар

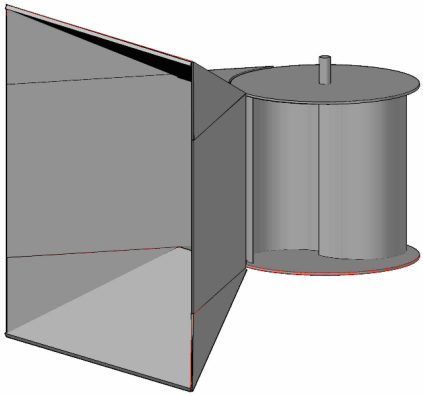


Figure 7 – Vertical change of the wind inlet angles
Рис. 7 – Вертикальное изменение угла конфузора для ветрового потока
Слика 7 – Вертикално померање угла уводника за ветар

The test procedure for examining the performance of the Savonius rotor with increased vertical angles of the top and bottom plates on the wind inlet is as follows: after increasing the vertical angles of the upper and lower plates of the Savonius rotor wind inlet for 15°, an anemometer is placed at a distance of about 170 cm from the wind inlet. The speed of the wind created by a 50 cm diameter fan with a motor of 1.5 kW is then set at 7 m/s. An example of this procedure can be seen in Figure 8. Then, the tachometer is used to measure the number of revolutions of the Savonius rotor as shown in Figure 9. The same test procedure is repeated for other angles.

Figure 8 – The process of measuring the wind speed using an anemometer
Рис. 8 – Измерение скорости ветра анемометром
Слика 8 – Поступак мерења брзине ветра помоћу анемометра

Figure 9 – Measurement of the number of rotor revolutions, where the vertical angle of the wind inlet is, in this case, increased for 15°
Рис. 9 – Измерение количества оборотов вращения ротора, при увеличении вертикального угла конфузора для ветрового потока на 15°
Слика 9 – Поступак мерења броја обртаја ротора, где је вертикални угао уводника за ветар у овом случају повећан за 15°

The results obtained after testing the vertical angles of the upper and lower plates of the wind inlet can be seen in Table 1. It can be seen here that the vertical wind inlet angle of 15° gives the best results with the maximum speed of 396 °/min.

Table 1 – Rotor RPM measured at different vertical angles of the wind inlet
Таблица 1 – Количество оборотов вращения ротора измерено под различными вертикальными углами конфузора для ветрового потока
Табела 1 – Број обртаја ротора мерен под различитим вертикалним угловима уводника за ветар

γ(°)	***n (rpm)***	
	Max	***min***
0	318	304
15	396	388
30	371	361
60	330	322
90	288	283
120	230	227

The effect of rotation speed depending on the vertical angle of the wind inlet can be seen in the diagram shown in Figure 10. Here one can clearly see that the angles of the upper and lower plates of the wind inlet of the Savonius rotor of 15°, 30° and 60° give a higher number of revolutions of the rotor relative to the vertical angle of the upper and lower plates of

the wind inlet of zero degrees, while, with increasing the angles of 90° and 120° , rotation speed drops.

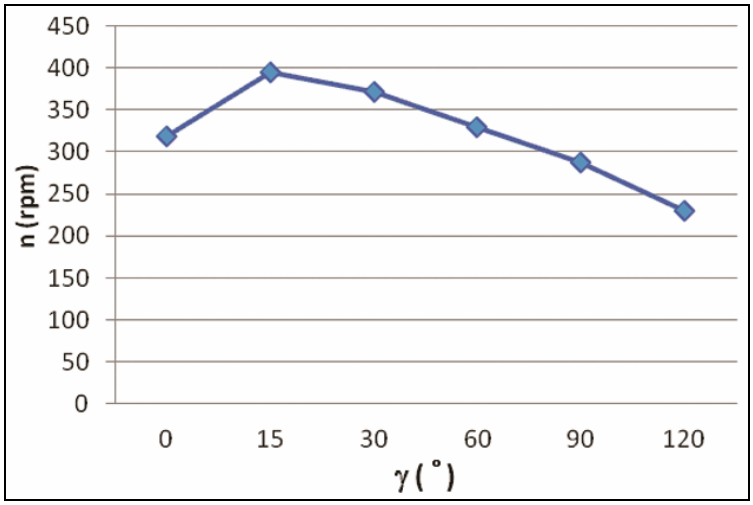


Figure 10 – Impact of the rotor rotation speed, taking into account different vertical angles of the wind inlet γ

Рис. 10 – Влияние скорости вращения ротора, с учетом разной величины вертикальных углов конфузора– γ

Слика 10 – Утицај брзине ротације ротора узимајући у обзир различите вертикалне углове уводника ветра γ

Conclusion

Due to high prices and limited resources of petroleum products which emit CO_2 into the air in the combustion process thus contributing to the greenhouse effect, renewable energy sources appear as the only alternative to the existing energies. Due to the changes in the economic relations of production and consumption, today more attention is paid to the rational use of energy. Wind energy is a huge potential that can meet energy needs. Wind generators are used to convert wind energy into mechanical energy and for electricity production.

What was new in this paper was to analyze design changes and move the vertical angles of the upper and lower plates of the Savonius rotor wind inlet, which has enhanced the Savonius rotor performance. The designed wind inlet was placed in front of the rotor in order to prevent negative torque opposed to rotor rotation. The geometric parameters of the wind inlet were optimized in order to obtain optimal performances. The analysis

found that the increase of the vertical angles of the upper and lower plates of the Savonius rotor wind inlet gives better results than using the classical wind inlet without increasing the vertical angles of the upper and lower plates. The angle of the upper and lower plates of the Savonius rotor wind inlet was gradually raised to 15°, 30°, 60°, 90° and 120°. It was found that the angles of 15°, 30° and 60° give higher numbers of rotor revolutions in relation to the wind inlet of the Savonius rotor whose value of the angle of the upper and lower plate is zero degrees. It was also found that the number of revolutions drops with the angles of 90° and 120 °. The best results are obtained with increasing vertical angles of the top and bottom plates of the wind inlet of the Savonius rotor for 15°, where the rotor speed is 395°/min.

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УЛУЧШЕНИЯ ЭКСПЛУАТАЦИОННЫХ СВОЙСТВ КОНФУЗОРА РОТОРА САВОНИУСА

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ВИД СТАТЬИ: профессиональная статья
ЯЗЫК СТАТЬИ: английский

Резюме:

В данной статье представлен анализ замены дизайна ротора Савониуса путем увеличения вертикальных углов верхней и нижней стенки конфузора, произведенной в целях улучшения эксплуатационных свойств системы. Конфузор для вихревого потока размещается фронтально для того чтобы предотвращать отрицательный крутящий момент противоположный вращению ротора. Анализ и испытания показали, что при учеличении вертикальных углов верхней и нижней стенки конфузора ротора Савониуса значительно улучшаются эксплуатационные свойства ротора. Выявлено, что наилучшие результаты достигаются при увеличении вертикальных углов верхней и нижней стенки конфузора ротора Савониус на 15° суммарно, при этом количество оборотов ротора достигает 395°/мин.

Ключевые слова: вертикальные углы, ветер, ротор Савониуса, роторы, стенки, конфузоры.

ПОБОЉШАНЕ ПЕРФОРМАНСЕ УВОДНИКА ЗА ВЕТАР САВОНИУСОВОГ РОТОРА

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ВРСТА ЧЛАНКА: стручни чланак
ЈЕЗИК ЧЛАНКА: енглески

Сажетак:

У раду је извршена анализа промене дизајна кроз повећање вертикалних углова горње и доње плоче уводника за ветар Савониусовог ротора, са циљем да се добију бољи резултати и

боље карактеристике система. Дизајн са уводником за ветар смештен је у предњем делу ротора како би се спречила негативна обртна сила супротна ротацији ротора. Геометријски параметри уводника за ветар су одређени како би се добиле оптималне перформансе. Анализом и испитивањем установљено је да се са повећањем вертикалних углова горње и доње плоче на уводнику за ветар Савониусовог ротора добијају боље перформансе ротора него само коришћењем класичног уводника за ветар. Утврђено је да се најбољи резултати постижу са повећањем вертикалних углова горње и доње плоче уводника за ветар Савониусовог ротора за укупно 15^{o}, где се добија број обртаја ротора 395^{o}/мин.

Кључне речи: вертикални углови, ветар, Савониусов ротор, ротори, плоче, уводници.

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USABILITY: KEY CHARACTERISTIC OF SOFTWARE QUALITY

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Summary:

The paper emphasizes the importance of software usability as a key quality characteristic of software during its use. At the beginning of the paper, a retrospective of formal definitions of usability is given in order to show the evolution of views on usability for more than three decades. To ensure the required quality in use, it is necessary to measure and evaluate many characteristics that affect the usability of software. The paper gives a brief chronology of attempts to identify different dimensions of usability based on its definitions. Since it is not easy to determine the characteristics that contribute most to the quality in use, two methods are applied in identifying the key attributes that affect usability, and they are to be given special consideration when building a model of usability.

Key words: ISO*, quality standard, software quality.*

Introduction

Usability is a qualitative feature of software during its use which allows the user to perform desired tasks easily, effectively and comfortably. Usability has a multi-dimensional character and cannot be viewed only from one point of view because it is influenced by various factors. In the literature, the term usability is widely used and means different things to different people. Usability is a key element in defining the overall quality of a software system and is commonly recognized as a quality factor in the technical aspect. This is a field of interaction of people and computers (HCI), which provides the theoretical background and suggests techniques for producing quality user interfaces. Usability can be seen as the usefulness and ease of use of the system. Usability also has several other aspects, including interface design, design functionality, data and metada-

ta and computer systems and networks (Arms, 2000). All these different aspects of usability are of interest to software designers, developers and users in order to get a usable system. Usability is often used in a different context where a precise meaning can be lost. Because of many aspects of usability, it is necessary to consider various definitions of usability and to analyze a comprehensive set of attributes that constitute usability in order to obtain a clear idea of usability.

Usability is a term that means "easy to use" in situations when a person interacts with the interface of the system and its functions; it plays an important role in the software development process. Usability is a measure of the usefulness of the proposed solutions, or the answer to the question of how easily and how effectively users can complete the desired task. Usability is primarily related to the quality of design applications and includes user interface design, method development, testing and commissioning.

Definitions of usability

Although the concept of usability plays an important role in the interaction between people and computers, there is still no universally accepted definition of usability. As a quality characteristics, usability is defined by different researchers and several ISO standards. A retrospective of formal definitions will be given further on in order to demonstrate how researchers' views on usability have changed over more than four decades.

As described earlier, based on the definitions of usability in the HCI field, researchers have identified various dimensions of usability. An appropriate definition of usability can act as a guideline for the development of an efficient software system, but there is still no definition consistently accepted by developers. Although several definitions of usability and its attributes have been proposed in the previous literature, an agreement on the concept of usability has not been reached yet between researchers and standardization bodies (Abran et al, 2003). Different views on the attributes of usability and the lack of authentic definitions of usability are the main reasons for poor usability of software systems. An analysis of different definitions of usability from different studies can help developers of software systems to develop an efficient and usable software system. The aim of this work is to see how the characteristics and their attributes are defined in previous studies.

In the study of Dubey et al. (Dubey et al, 2010, pp.4723-4729) 37 formal definitions are examined, and a total of 152 attributes are allocated and grouped into 22 categories. They found that, in the above definitions,

the most often used usability attributes are: learnability, satisfaction, flexibility, efficiency, effectiveness and ease of memorization. However, the drawback of this study is the fact that it considers only the publications with the definitions of usability from a single source (citation database Scopus index) published before 2010.

Below is a chronological summary of the examined attributes of usability in different models, definitions and standards, from 1977 to 2012.

The first and most widely used software quality model was proposed by McCall (1977) who describes usability as operability, training and communicativeness. Eason (1984) characterizes usability in three independent parts (the characteristics of the task, the user and the system) on the platform on which the task is performed and with the users' reaction, which is a variable. Makoid (1985) proposes that different definitions of usability may include various parameters (customer satisfaction, error type). Butler (1985) suggests that the system is considered usable if users can complete a specific task within a predetermined period of time. Reed (1986) defines usability as ease with which the system can be learnt and used. In the same year, Shack introduced an operational definition of usability that allows to evaluate the system during the development life cycle. He presented one of the most commonly used definitions of usability indicating that the system is useful to the extent to which it is effective, easy to learn, flexible and subjectively friendly. Gould (1988) classifies the usability with regard to the system performance, system functions and user interface (Dubey et al, 2010, pp.4723-4729).

Booth (Booth, 1989) finds it difficult to identify and measure the flexibility of the system and believes that usefulness should be the basis for usability. He modifies Shackel's criteria and states that usability has four factors: usefulness, efficiency, ease of learning (or ease of use) and attitude (or appeal).

Later, Shackel and Richardson (1991) recognized the importance of usability engineering and suggested four important characteristics of usability called learnability, efficiency, flexibility and attitude?. Efficiency refers to the impact of the implementation of tasks, learnability implies a degree of learning to achieve tasks, the flexibility is the ability to adapt to task changes and attitude relates to customers' satisfaction in the work with the system.

Bevan et al. (1991) argue that usability is based on the product, the user, ease of use and acceptability of the product for a specific class of users to perform specific tasks in a specific environment. In the quality model proposed in 1992 by Grady called FURPS (Functionality, Usability, Reliability, Performance, and Supportability), usability includes human fac-

tors, aesthetics, consistency in the user interface, online and context sensitive help, wizards and agents, user documentation and training materials (Dubey et al, 2010, pp.4723-4729).

The ISO 9126 (ISO/IEC 9126, 1991) definition contains 21 attributes arranged in six areas: functionality, reliability, usability, efficiency, maintainability and portability, out of which usability attracted the attention of most researchers.

In 1992, the Institute of Electrical and Electronics Engineers (IEEE Std 1061) defined usability as: the ease with which users can learn to operate, prepare input and interpret the results of a system or a component and proposed a model that usability depends on the following factors: user-friendliness, ease of learning and communicativeness. Hix and Hartson (1993) define usability via performance, ease of learning, knowledge retention over time, advanced functions of use, the first impression and long-term user satisfaction. Löwgren (1993) stated that usability is the result of relevance, efficiency, ease of learning and attitude (Dubey et al, 2010, pp.4723-4729).

Nielsen (Nielsen, 1993) recognizes usability as an important attribute that affects the acceptance of the product. Usability and complaisance can help product utility that enhances the users' ability to perform their tasks. He divides acceptability to practical and social acceptability and identifies five important attributes associated with usability, which are: learnability, efficiency, memorability, errors and satisfaction. Social acceptability indicates whether the system is designed for ethical purposes. Practical acceptability is a generalization about the acceptance of system costs, compatibility with existing systems, reliability, availability, usefulness and other such considerations. Usefulness refers to the question whether the system can be used to achieve a desired goal. Usefulness can be further divided into usability and utility. Utility is related to forecasting functionality of the system to do what is necessary. Usability is a question of how well users can use this functionality. So, all these elements of the system of acceptability are very important for a general attitude. Usability is only one of many, but still needs to be one of the criteria for evaluating software or services.

The SUMI method of measurement (Software Usability Measurement Inventory) also describes usability by its attributes: efficiency, effectiveness, helpfulness, control and ease of learning (1993). Dumas and Redish (1993) suggest that usability means that people who use the product can quickly and easily accomplish their tasks and it focuses on four main points: users, productivity, tasks, and ease of use (Dubey et al, 2010, pp.4723-4729).

Rubin (Rubin, 1994) said that likeability is also an important usability attribute that represents the user's perception, feelings and opinions about the product.

Luis (1995) introduced a questionnaire PSSUQ (Post Study System Usability Questionnaire) which identifies usability attributes grouped into three factors, ie. usefulness of the system, the quality of information and the quality of the interface. Thomas (1998) categorizes the attributes into the result, the process and the task. In their model, Dix et al. (1998) represent system usability in three categories: ease of learning, flexibility and robustness (Dubey et al, 2010, pp.4723-4729).

After that, the International Organization for Standardization (ISO) published usability standards from two different points of view on usability, i.e. ease of use (ISO 9241-11, 1998) and quality in use (ISO/IEC 9126-1, 2001). ISO 9241-11 establishes the effectiveness, efficiency and satisfaction as the basic dimensions and defines usability as an extent to which a product can be used by specified users to achieve specified goals with effectiveness, efficiency and satisfaction in a specified context of use (ISO 9214-11, 1998).

Lecerof et al. (1998) provide a definition of usability, addressing the importance of user needs, efficiency, subjective feelings of users, ease of learning and system security function, such as giving users the rights to nullify actions that can lead to errors. Clairmont et al. (1999) suggest that usability is a degree to which the user can successfully learn and use the product to achieve the goal. Arms (2000) states that usability has several aspects, including interface design, functional design, data and metadata of computer systems and networks alike. Frojkaer et al. (2000) argue that the components of effectiveness, efficiency and satisfaction should be considered as separate and independent aspects of usability. Doniaee et al. (2001) developed an integrated model of measuring quality in use (QUIM). The attributes included in QUIM are: effectiveness, efficiency, satisfaction, productivity, safety, accessibility and internationalization. Battleson et al. (2001) proposed to improve the interface usability so that it can be easy to learn, remember and use, with few mistakes for target users and designed to support specific tasks (Dubey et al, 2010, pp.4723-4729).

A little later, ISO 9126, 2001, established the following usability subatributes called: user-friendliness, ease of learning, functionality, attractiveness and usability compliance. An Oulan and Pajarillo's study, called CUNY + (2002), primarily used a questionnaire as a method of evaluating usability. The authors conducted a study in two stages to compare the usability of text-based and Web-based CUNY Web sites. The criteria applied were impact, efficiency, control, attentiveness and adaptability

(Dubey et al, 2010, pp.4723-4729). Blandford et al. (2002) indicate that usability is technically, cognitively, socially and design-oriented and that it is important to gather these different perspectives together. Brinck et al. (2002) suggested that usability be: functional correctness, efficiency of use, ease of learning, ease of remembering, error tolerance and a subjective feeling of comfort. Abran et al. (2003) combine the attributes of ISO 9126 and ISO 9241 and develop a new model with the attributes: efficiency, satisfaction, ease of learning and safety. To describe the usable software systems, Bas et al. (2003) have qualities such as interchangeability, flexibility, re-use, performance, security, etc. Campbell et al. (2003) explicitly state that usability refers to the relationship between tools and their users. Shneiderman et al. (2005) identified five measures of usability, namely: learning time, speed, error rate profile, retention of knowledge over time and subjective satisfaction. Jeng (2005) also used efficiency, satisfaction and ease of learning as the attributes of usability for digital libraries. It identifies inherent and obvious usability. Inherent usability is inseparable and makes the product easy to understand, easy to learn, efficient to use, comfortable to use and with fewer errors while obvious usability is related to a visual impression of the interface. Krug (2006) looked at usability from a user's perspective with the need for an intuitive experience.

In 2006, Seffah et al. developed a consolidated model for measuring usability and metrics, called QUIM (Quality and Use Integrated Measurement). They combined different standards and models, such as ISO 9241 and ISO 9126, in one single consolidated, hierarchical model. They give the methods for determining the quality requirements as well as the identification, implementation, analysis and evaluation of the process and product quality metrics. This initial model is suitable for users who have little knowledge of usability and can be applied by both usability experts and not experts. The QUIM model consists of 10 factors (efficiency, effectiveness, satisfaction, ease of learning, productivity, security, trust, accessibility, usability and universality), divided into 26 measurable criteria that include 127 specific metrics. The model is used to measure the actual use of the software in operation and to identify problems. The QUIM model connects the factors with the criteria and metrics in a clear and consistent manner. It can be used in a general form or it can be adapted to a specific context (Dubey et al, 2010, pp.4723-4729).

Juristo et al. (2007) presented certain characteristics of usability, getting inspiration from a number of real applications. Seffah (2008) argues that there is a need to develop new environment for usability testing and methodology, since technical environment is developing and the current

laboratories are limited. Sauro et al. (2009) calculated the correlation of usability attributes from 90 different studies such as time on task, degree of completed tasks, errors, satisfaction upon task completion and satisfaction after testing. The results of this research have helped to clarify the attributes that have contributed to the connection of the structure of usability studies. Bevan (2009) argues that, despite the authoritarian nature of international standards for usability, many of them are not widely used (Dubey et al, 2010).

The Website Evaluation Framework (WEF) model consists of five quality characteristics (Zhou, 2009): aesthetics, ease of use, multimedia, rich content, and reputation. Oztekin proposes the UWIS methodology that integrates established dimensions of the quality of web services (reliability, integration of communications, navigation, control, security, accountability and quality of information) and usability of information systems (efficiency, effectiveness and satisfaction) (Oztekin et al, 2009, pp.2038-2050). Gardner-Bonneau (2010) discusses how much human factors and usability of the system will be effective when there are more and more changes in the technological environment (Dubey et al, 2010). According to Rhodes (Rhodes, 2010), usability is further subdivided into five important factors or attributes of the user interface as follows: efficiency, ease of learning, memorability, error rate and satisfaction. According to a survey (Karahoca et al, 2010, pp.5813-5819), the elements of usability are ease of learning and efficiency, aesthetics and navigation, content and functionality, accuracy and consistency, technical adequacy, help and documentation and debugging.

From 2011 until today, the current standard in the field of software quality has been ISO 25010, which represents the second generation of standards for software quality, and was issued with the intent to define the reference models and the quality of the evaluation process which will replace the ISO/IEC 9126 and ISO/IEC 14598 series. At present, the current series of international standards (SQuaRE) includes two models of quality: quality model in use and the quality of the product model (ISO/IEC 25010). However, ISO 25010 does not include the quality of information because ISO 25012 is intended for this purpose. This standard is a general model for data quality and is intended to be used together with ISO 25010. It aims to establish standards in data quality as well as in planning and performing data quality assessment.

Figure 1 is a graph showing a model of quality in ISO/IEC 25010 (SQuaRE).

These definitions of usability are usually used to identify usability problems of traditional graphic user interfaces. However, the emergence of

the Internet as a basic working and development environment with its specific properties contributes to the speedy development and massive use of Web-based applications that are a rather specific software product. Although some of these definitions of usability can be equally successfully applied to a variety of web applications, the need for a positive user experience in interacting with the application is further emphasized in the web environment.

Some researchers in the field of quality of web applications (Bublione, 2002), (Becker and Olsina, 2010), (Olsina and Molina, 2008, pp.385-420), (Lew and Olsina, 2011, pp.214-229) indicate that the characteristics of software quality given in the ISO/IEC standard quality models (ISO 25010) are not sufficient to describe the quality of specific software products such as Web applications.

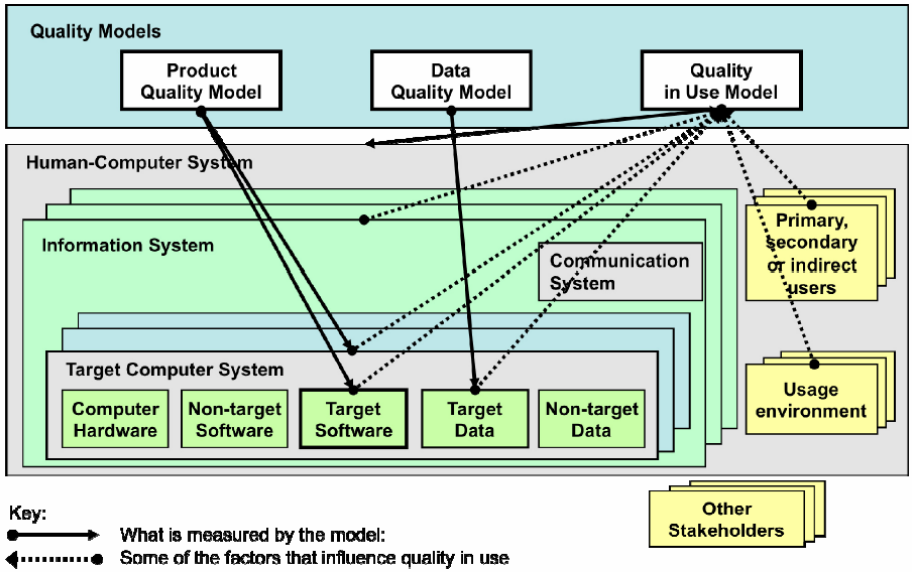

Figure 1 – Models of quality in SQuaRE
Puc. 1 – Модели качества в системе SQuaRE
Слика 1 – Модели квалитета у SQuaRE

Research efforts over the past decade have given a number of models of software quality of Web applications oriented to a specific domain. Thus we have the quality designs for specific domains such as e-Learning (Chua and Dyson, 2004, pp.184-190), (Bhuasiri et al, 2011, pp.843-855), (Kasse and Balunywa, 2013), e-commerce (Loiacono et al, 2002), (Barnes and Vidgen, 2002, pp.114-127), (Lee and Kozar, 2006, pp.1383-1401), (Lazić, 2010), hospitality (Spremić et al., 2008, pp.229-238), e-banking

(Moraga et al, 2008, pp.113-129), academic sites (Olsina et al ., 2001), public administration (Quirchmayr et al, 2007) and so on. In addition, there are a lot of general quality models tailored specifically for Web applications, such as (Olsina and Rossi, 2002, pp.20-29), (Li and Suomi, 2009), (Montero et al, 2008, pp.220-233), (Bjarnik, 2001), (Offut, 2003) and (Bublione, 2002).

Decomposition of usability

To ensure the required quality in use, it is necessary to measure and evaluate many characteristics that allow us to determine the usability of software, where metrics play an important role. The main problem with the definition of the product is that it is very difficult to determine its characteristics and their attributes that need special consideration. Only a few models of software quality solve the aspect of usability in a detailed and structured way (Abran et al, 2003, pp.325-338).

The previous section provides a broader and chronological set of different standards and studies with formal definitions of usability and quality models which are the basis for further work. In order to isolate those attributes that influence usability the most, two approaches were used: the first one analyzes the attributes of usability in various formal definitions of usability, and the other one analyzes the attributes in the key usability models.

The first approach involves analyzing the contents of all formal definitions given in the reviewed publications and extracting the key attributes of usability. The selected attributes are analyzed, followed by the identification of their characteristics, based on which they are grouped into certain categories of usability attributes. However, it has been noted that the proposed definitions are informal, too short and ambiguous.

In the formal definitions presented in the previous chapter, the author has identified 186 different attributes which are grouped under 22 different categories. Out of all attributes, 21 appear 2 or more times (total 154 frequencies) and they are grouped in a separate category, while 32 attributes appear only once and they are grouped under the name "others".

The usability attributes and their frequency of occurrence in the reviewed standards and studies are shown in Table 1. They are arranged in the descending order, from the attributes with the highest frequency in the top of the table to the last attribute with the smallest number of occurrences.

For the ease of analysis, the frequency of usability attributes in the reviewed studies and standards is shown graphically in Figure 2. Based on the overall frequency of attributes in all included definitions, it can be concluded that the attributes: ease of learning, satisfaction, flexibility,

efficiency, effectiveness and ease of memory have the highest impact on the usability of software systems.

Another approach examines the key attributes of usability in usability models proposed by researchers and international standard organizations (Eason, 1984), (Shackel, 1991), (Nielsen, 1993), (ISO 9241-11, 1998), (ISO 9126, 2001), QUIM model (Seffah et al, 2006), (ISO 25010, 2010), etc.

Although all models have many different attributes, the analysis of their common characteristics has pointed to their similarities. Based on the studies on the similarities between usability models and the frequency of attribute occurrence in all discussed usability models, it can be concluded that 5 attributes (effectiveness, efficiency, satisfaction, ease of learning and accessibility), have the biggest impact on software usability. Table 2 shows the usability attributes in the discussed usability models and their frequency of occurrence.

Table 1 – Reviewed usability attributes and their frequency
Таблица 1 – Обзорные атрибуты применяемости и их частотность
Табела 1 – Прегледани атрибути употребљивости и њихова учесталост

Attributes	Frequency	Percent
The ease of learning	23	12.4%
Satisfaction	18	9.7%
Flexibility	16	8.6%
Efficiency	18	9.7%
Effectiveness	12	6.5%
The ease of memory	8	4.3%
Interface Design	7	3.8%
The ease of use	6	3.2%
Errors	5	2.7%
Safety	5	2.7%
Help	5	2.7%
Functionality	4	2.2%
Communications	4	2.2%
Task	4	2.2%
User	4	2.2%
Productivity	3	1.6%
The first impression	3	1.6%
Tolerance to errors	3	1.6%
Advanced Features	2	1.1%
Operability	2	1.1%
Training	2	1.1%
Other	32	17.2%
Total	186	100.0%

The comparative analysis of the results of the two approaches can result in a conclusion that the characteristics: effectiveness, efficiency, satisfaction, ease of learning and flexibility have the highest impact on the usability of software.

Effectiveness is a measure of the system performance to successfully complete a specific task or goal in time.

Efficiency refers to the accuracy and completeness of a certain objective and represents the successful completion of the task using the system.

Satisfaction is a pleasant feeling that a user gets during or after the use of the system. It can be seen as appeal or acceptability of the system by the user, in this context of use.

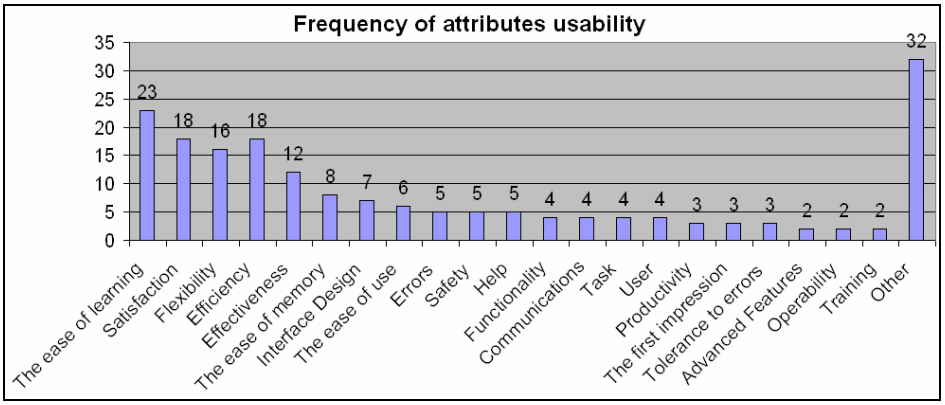

Figure 2 – Frequency of the usability attributes in the reviewed standards and studies
Рис. 2 – Частотность атрибутов применяемости по стандартам и исследованиям
Слика 2 – Фреквенција атрибута употребљивости у прегледаним стандардима и студијама

Table 2 – Comparison of the usability models
Таблица 2 – Сравнение моделей применяемости
Табела 2 – Поређење модела употребљивости

Attributes of usability	Eason (1984)	Shackel (1991)	Nielsen (1993)	ISO 9241-11 (1998)	ISO 9126 (2001)	QUIM (2006)	ISO 25010 (2011)
Efficiency		√		√		√	√
Effectiveness	√		√	√		√	√
Satisfaction			√	√		√	√
The ease of learning	√	√	√		√	√	√
Accessibility						√	√

The ease of learning is the ability of the software product to enable the user to learn its application. The system should be easy to learn and understand. It should be easy for the user to carry out a task using the software system. It also includes the effort needed to understand and work with an unfamiliar system, the user's additional time for learning as well as user's training after certain time from the time of installation of the system.

Flexibility represents the variations in the system work relating to an existing one, such as flexibility to the context in use, accessibility in use or expandability to the context in use.

Conclusion

The characteristics of today's business world (global networking - Internet, software dependence, Web applications, etc.) emphasize the need for predictive usability of software in an easy and user-friendly way. Today, there are numerous methods for assessing usability. As a result, there is the question of choice of the most appropriate method for assessing the usability of a particular software product. The choice of an adequate method can significantly improve the efficiency of the evaluation process and usability of the software product. Choosing the right method is not an easy task, since it depends not only on the type of the software product, but also on the development of the objectives of the project and the context of use; therefore, it would be necessary to have an effective formal mechanism for assessing the usability of a product to be supplied. In fact, the choice of method is conditioned by various criteria, some of the most important being the resources required to perform the method (time, money, the number of evaluators and their expertise, the number of users for testing, place and test equipment), the required level of objectivity and the possibility of applying the method in different application development stages.

The quality models defined by the current ISO standards are too general to cover all application domains, and most practitioners only use them as a guide or a starting point for quality modeling and measurement. Of course, it is not possible to measure all the internal and external characteristics, or to measure quality in use in all possible cases. Together, quality models serve as a framework that ensures taking into account all the quality characteristics.

Although we intuitively know what usability is, it is not easy to formalize a set of characteristics that contribute to good usability. In addition, we often turn to those attributes that are useful and easy to measure rather than to those that are really necessary.

In order to understand and measure usability, it is necessary to build a model of usability first. One of the most important areas of usability research focuses on usability attributes, principles and characteristics. To define a usability model for a particular domain of software use means to face the question, "Which quality characteristics are to be included in the model and what are the relations between them?".

Usability models are conceptual views which determine key areas to demonstrate the usability of existing software. The analysis of different usability models proposed by researchers and international organizations for standards can help in identifying the key attributes that affect the usability of a software system and in developing efficient and usable software systems.

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ПРИМЕНЯЕМОСТЬ: КЛЮЧЕВАЯ ХАРАКТЕРИСТИКА КАЧЕСТВА ПРОГРАММНОГО ОБЕСПЕЧЕНИЯ

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ЯЗЫК СТАТЬИ: английский

Резюме:

В данной статье подчеркнуто значение применяемости программного обеспечения, как ключевой характеристики качества программного обеспечения в процессе его использования. В вводной части статьи представлено обозрение определений применяемости, в котором прослежена эволюция взглядов исследователей в отношении применяемости за последние тридцать лет.

Для обеспечения соответствующего качества в использовании, необходимо измерять и оценивать различные

характеристики, влияющие на применяемость программного обеспечения. В работе приведен хронологический обзор попыток идентификации различной частотности применяемости, предпринятых разными исследователями на основании определений применяемости.

Учитывая, что не всегда легко удается определить какие именно характеристики способствуют качественному использованию, автор статьи применил два метода идентификации ключевых атрибутов, влияющих на применяемость, которые необходимо иметь в виду при разработке модели применяемости.

Ключевые слова: характеристики качества, качество программного обеспечения, применяемость программного обеспечения.

УПОТРЕБЉИВОСТ КАО КЉУЧНА КАРАКТЕРИСТИКА КВАЛИТЕТА СОФТВЕРА

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ВРСТА ЧЛАНКА: стручни чланак
ЈЕЗИК ЧЛАНКА: енглески

Сажетак:

У раду је наглашен значај употребљивости софтвера као кључне карактеристике квалитета софтвера приликом његове употребе. Представљена је и ретроспектива формалних дефиниција употребљивости, са намером да се покаже еволуција погледа истраживача на употребљивост током више од три деценије. Да би се обезбедио захтевани квалитет при употреби потребно је мерити и вредновати многе карактеристике које утичу на употребљивост софтвера. Такође, хронолошки су приказани покушаји истраживача да на основу дефиниција употребљивости идентификују њене различите димензије. Имајући у виду да није лако одредити карактеристике које највише доприносе квалитету при употреби, у раду су примењене две методе за идентификовање кључних атрибута који утичу на употребљивост, а које треба посебно размотрити приликом изградње њеног модела.

Кључне речи: карактеристике квалитета, квалитет софтвера, употребљивост софтвера.

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MODEL FOR PKI INTEROPERABILITY IN SERBIA

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Abstract:

The increasing use of electronic services that use electronic certificates and the increasing implementation of public key infrastructures require their interconnection and interoperability. In this paper, the authors analyze the models for interoperability between various PKI domains and their possible application in achieving interoperability of the public key infrastructures in the Republic of Serbia. The implementation of the interoperability of the existing models is discussed from the following aspects: scalability, processing of certification paths, implementing policies, the points of failure and the possibilities of re-establishing trust. We proposed a conceptual model based on the Bridge Certification Authority trust model. This model can provide the establishment of the interoperability of both the existing and new national PKI domains, their interconnection as well as their connection with foreign PKI domains. The model was extended with the Validation Authority that provides more efficient processing of the certification path.

Key words: *model, interoperability, PKI, certification authority, certificate.*

Introduction

The companies use the Internet for global business, which means that their information resources are distributed in more places. Therefore, di-

scussions about the elimination of security risks should consider distributed security architecture. The Public Key Infrastructure (PKI) technology is applied in distributed security architecture (Pfleeger, Pfleeger, 2006).

Companies can use electronic certificates (hereinafter: certificates) for electronic services which are issued by different certification authorities from different PKI domains. In order to ensure the functioning of electronic services which use PKI certificates from different domains, there should be a mutual link between them, i.e. it is necessary to establish interoperability for common work of two or more PKI domains.

The main problem with the connection of certification authorities from different PKI domains is certification path discovering and processing, as well as the validation of the user certificate. This problem is overcome by using an appropriate interoperability model.

In the Republic of Serbia (hereinafter: R. Serbia) there are more independent certification authorities which issue electronic certificates and (or) qualified certificates. While researching the Certificate Policies and the Certification Practice Statements of the accredited certification authorities, together with the data from the official websites of the certification authorities in R. Serbia, we have concluded that there is neither connection nor any form of interoperability between the PKI architectures of the authorities whose certifications are registered or recorded. Also, there is no PKI interoperability with other countries.

One form of the distribution trust through the Windows operating system has been achieved by the Serbian Post Certification Authority which became a member of the Microsoft's "Windows Root Certificate" program in September 2009.

The paper (Pavlović, 2007) proposes a possible way for realizing the national PKI. This solution is based on the existence of the Central Root Certification Authority which signs government certification authorities and on the existence of the Bridge Certification Authority through which the government PKI architecture is linked with PKI architectures of non-government organizations (NGOs) and PKI architectures of other countries. Today, this approach would cause numerous problems in the existing government PKI architectures. The authors (Prodanović, Vulić, 2011) propose to form a Bridge Certification Authority which would create a relation of trust with current and future governmental and NGOs PKI architectures, as well as with PKI architectures of other countries. This approach does not require the re-establishment of PKI architectures but the exchange of cross-certificates and the definition of certificate constraints. The problem of this solution is the complexity of processing the certification path.

The proposed PKI interoperability model is aimed to contribute to the realization of the connection of the existing PKI domains, future PKI domains, their interconnection, and their connection with PKI domains of other countries. The model also proposes a mechanism for processing certification paths.

The paper explains PKI, then considers the types of PKI interoperability models and, finally, it analyzes possibilities of applying the described models on the PKI of R. Serbia. A conceptual model of the R. Serbia PKI interoperability is proposed, followed by the conclusion.

Public Key Infrastructure

Since the Internet and intranet are distributed environments, it can be said that PKI with its capabilities represents modern security architecture to protect and securely distribute information in distributed environment.

PKI is a complex system that consists of hardware, software, people, policies and procedures necessary for the creation, management, distribution, use, PKI storage and revocation of electronic certificates and public key cryptography management (Adams, Lloyd, 2003, pp.11-15).

PKI enables the establishment of connections between public keys and entities (in the form of certificates), checks the connections by other entities and enables services necessary for key management in distributed systems.

PKI provides a trusted environment for the transmission of information in distributed systems by providing:

- Authenticity of the parties to the communication - the participants in the communication are checked,
- Message integrity - guarantees that messages have not been changed during transmission,
- Non-repudiation of sending and receiving - the participants in communication cannot deny sending or receiving messages,
- Confidentiality of the message - the message content can be found out only by the entity to whom a message is intended.

Today, PKI is applied in many applications and protocols such as Secure Sockets Layer (SSL), Secure Multipurpose Internet Mail Extensions (S/MIME), IP Security (IPSec), Secure Electronic Transactions (SET) and Pretty Good Privacy (PGP).

The OASIS Research (2003) has shown that PKI is mostly applied to: electronic signatures, web servers (SSL), protection of e-mail and web

services, virtual private networks (VPN), e-commerce, protection of wireless networks (Wi-Fi), code protection and network authentication.

Due to growing needs of financial institutions, companies, government agencies, health and other organizations to use the Internet for their business, information security has become an essential as well as a more complex element of security operations. Not only do organizations have to protect their information and maintain trust with partners but also they have to comply with the government and other standards which relate to the security of operations.

The Components of PKI Architecture

The PKI architecture model is composed of five components specified in (Arsenault, Turner, 2003): the certification authority, the registration authority, PKI Repositories, archives, end entities and their mutual relationships. The PKI architecture model, its functional components and their interconnection are shown in Figure 1.

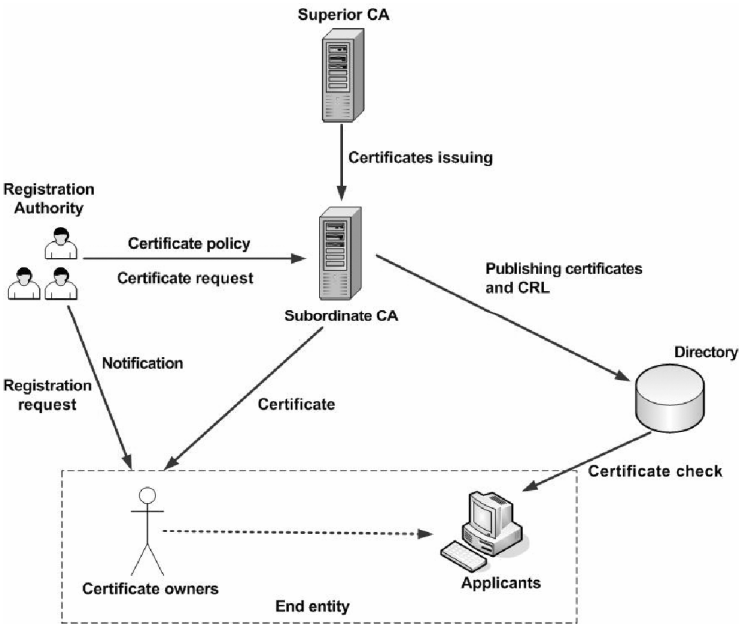

Figure 1 – The relationship between the PKI components
Рис. 1 – Иерархическая архитектура PKI
Слика 1 – Међусобни однос компоненти PKI

The Certification Authority (CA) is a collection of computer hardware, software and human resources. It is responsible for issuing certificates

(created and signed), managing information on the status of certificates and Certificate Revocation Lists (CRLs), publishing certificates and CRLs, and managing archives of expired certificates. The CA can delegate responsibilities to other infrastructure components. It most often works together with the registration authority which is responsible for the identification of entities applying for the issuance of certificates (Prodanović, 2007), (Prodanović, Petrović, 2006).

The Registration Authority (RA) (Sheehy, et al, 2011) is a confidential representative of the CA responsible for verifying the identity of an applicant for a certificate. In addition, the RA can perform other functions which the CA has conveyed to it such as providing reports of revoked certificates, generating key pairs or archiving keys. The RA cannot issue certificates or generate CRLs.

The PKI repository provides storage of certificates and information about their status. The PKI database must fulfill the following requirements: a simple and standardized approach, modern way of data storage, built-in protection, data management and the possibility of storing similar data. The database is implemented as a directory according to standard X.500. The directory stores and distributes certificates and manages their changes. PKI applications access the directory through the LDAP (Lightweight Directory Access Protocol) (Johner, et al, 2000) protocol which is a customized version of the DAP (Directory Access Protocol) protocol.

Archives. The archives contain stored CA certificates for a longer period of time. Archives must guarantee that certificates have not been and will not be changed while they are in the archives. Before the certificate issued by the CA is stored to the archives, it is necessary to determine whether the certificate comes from the CA and whether it is valid. The certificates are stored in the archives so that some signatures of older documents could be verified.

End Entity (End-Entity, EE) is defined as a user of PKI certificates and (or) end user of a system that is the subject of the certificate (Arsenault, Turner, 2003). In other words, in the PKI system, the end entity is a general term for a subject that uses any services or functionality of the PKI system and it can be the owner of a certificate (individuals, organizations or other entities) or the applicant (may be an application, service, CA, etc.) for a certificate or a CRL. The term PKI users is often used and it refers to organizations or individuals that use PKI, but do not issue certificates. They rely on other companies that publish certificates and verify certificates of other entities in the business.

Certificate. The purpose of the certificate is to establish a link between an identified (notified) entity and the public key, indirectly with the core-

sponding private key of the entity. This is accomplished when the CA uses its private key for signing the certificate, so that the certificate can be later verified by any entity which has the public key of the CA. The latest version of X.509 standard for the certificate structure published in 2000 defines a new set of additional certificate extensions. However, this set of extensions does not require the issuance of a new version of the certificate because these extensions can be included in version v3 which is specified by the IETF (Cooper, et al, 2008).

The Interoperability of PKIs

There is an increasing growth in requirements for the interoperability of PKIs. The full potential of PKI-based electronic services can be achieved only if large organizations provide certificates for e-business and if there is interoperability between PKIs.

In order to establish PKI interoperability, it is necessary to establish two processes of interoperability, namely:

- Political or contractual process of establishing mutual recognition. This process is necessary to determine whether the participants of interoperability comply with certain technical, security and management requirements for interoperability, prior to proceeding with the implementation of technical interoperability.
- The technical solution for the transfer of mutual recognition. This solution is used in order to transfer enough information on participant's status of interoperability so that the recipient of the certificate can automatically decide whether to accept or not a certificate from another PKI domain.

The policy of PKI interoperability involves determining the trusted PKI domain having the required level of security. Technical PKI interoperability includes processing certification paths through different PKI domains in order to discover certification paths and determine the validity of the certificate.

Interoperability can be perceived through three categories: interoperability between applications, between the components and between PKI domains (PKI Forum, 2001).

Interoperability between applications allows different PKI applications to be interoperable with one another, regardless of who has produced them. When manufacturers develop applications, in order to achieve interoperability of the PKI environment, they consider ways for storing credentials as well as the compatibility between different files and message formats (eg. the size of keys and algorithms should be compatible between different applications) and the communication between different applications.

Interoperability between components enables numerous PKI components to work together in order to get an overall functionality of the PKI solution. This interoperability is important because errors in the communication between the components cause the interruption of PKI functionality. In order to preserve interoperability between PKI components during development, it is necessary to use common protocols and message formats for communication between various components such as the CA, the RA and clients. The standards that ensure interoperability between components are: Public Key Infrastructure standard X.509 Certificate Management Protocol (PKIX-CMP) and Public Key Infrastructure standard X.509 Certificate Request Message Format (PKIX-CRMF). Also, it is necessary to use the most common mechanisms for providing information about the revoked certificates, such as the Online Certificate Status Protocol (OCSP) and the Certificate Revocation List (CRL). No less important in terms of interoperability is the implementation of authentication methods and cryptographic algorithms.

Interdomain interoperability focuses on establishing relations of trust between different PKI domains. This interoperability, besides characteristic problems, includes problems that stem from the interoperability of applications or components. Besides that, keeping in mind the technological solutions associated with these issues, this interoperability requires the existence of questions to the answers related to policies. When considering this type of interoperability, it is necessary to consider the availability of the public key between the domain and the general policies of the PKI domain. In addition, each domain should remain faithful to the set of policies that govern its certification process. The most important aspect of this interoperability is the support to cross-certification between CAs. The cross-certification can be implemented using a PKIX-CMP and other PKCS standards such as PKCS # 7 and PKCS # 10.

Models of PKI interoperability

The obvious approach to solving PKI interoperability is the existence of a central CA, or a point of trust. The hierarchical model includes a centralized control and unanimous support. There are other solutions that are more flexible, such as (Connolly et al, 2005): cross-certification model, cross-recognition model, bridge model and certificate trust list model.

A single (root) CA model is based on the existence of a CA which issues certificates to all users who trust it and thus realizes the trust in their mutual transactions. This model is sensitive to an increase in number of

users, which causes technical and administrative overhead of PKI schemes at the state level; it also causes the multiplicity of requirements that a CA cannot fulfill or a refusal to accept a CA, thus causing the CA security breach which affects all users.

Strict hierarchy model. This model extends the model with a single CA and allows specialization between CAs. With this model, users need to be persuaded to trust the root CA, even if it does not directly issue certificates. In this model, the root CA is a critical point of security. Compromising the root CA causes the failure of the whole PKI. In addition, the problem may be that the root CA, by its policies, imposes restrictions on subordinate CAs. This model does not have the problem of interoperability and it is suitable for use in centralized systems.

Cross-certification (mash) model. In this model, CAs establish relations of trust according to whether they trust each other. The user can trust an unknown CA across the certification path that leads to a local trusted CA. However, the establishment of interoperability across the network certification is technically and logistically challenging. Interoperability is not easily achievable between two CAs only by co-ordinating their policies and technical systems. The problem of interoperability is complicated as the number of cross-certifications grows even faster. The very nature of this model, where CAs are not familiar to each other, is not an ideal approach to establishing a multinational PKI. This model is most suitable for two or three related CAs which are required to interoperate with each other.

Bridge CA model. This model implies the existence of a central CA that achieves a bidirectional trust relationship with one CA of each PKI. It represents a communication channel between the CAs that it connects, i.e. interoperability is accomplished through it. This combines the aspects of the root model and the mash model. The bridge CA model provides simpler administration because it is required to establish only one pair of cross-certifications with each CA rather than n^2 certifications (n is the number of CAs) in a complete mash model. This model does not impose as strict technical requirements as the mash model. With its policy, the bridge model sets minimum requirements for connecting PKIs. The model is focused on the tasks of providing interoperability and that helps to centralize the management of interoperability problems in one organ that can develop and promote best practices. This model allows the connection of different models into one.

Cross-recognition model. In this model, a particular CA or PKI domain agrees to admit other CA or the PKI domain before a lower level of technical solutions is built. This means that the user from one PKI domain can use the information of the authority in the other PKI domain for authentica-

tion and vice versa. This model requires a close cooperation between the CAs at the administrative level or the existence of an agency for accreditation at the higher level. Cross-recognition allows formal and reciprocal recognition by the competent PKI authorities (top trust point) of the new PKI domain to impose, manage and enforce PKI trust standards and processes for accepting trust certificates in recognized fields. This allows that the users of one PKI domain can rely on the certificates issued by another domain for use in certain applications within the limits of accredited certification policy. This model does not guarantee the status and reliability of foreign certificates. Cross-recognition differs from cross-certification because there is no mutual recognition between CAs. The reason is that the model of recognition is based on the concept of an independent CA, which is licensed and accredited in order to achieve mutual recognition of CAs. The model of recognition avoids some of the technical interoperability issues.

Certificate trust list model. This model involves a list of CAs from trusted certification authorities. The list is electronically signed to ensure its integrity. These lists are simple and provide confidential communications. In this way, they avoid a need for a complex cross-certification process. These lists have led to the web model that represents the most widespread PKI interoperability across web browsers. The essence of this model is that the certificate user trusts the issuer of the certificate trust list, and therefore believes CAs in the list.

Accreditation certificate model. This model was proposed by the Australian Government during the development of Australia's PKI (Lloyd et al, 2001), (Australian Government, 2009). The model introduces the accreditation certificate which confirms that the CA is accredited by the Australian Government. In essence, each accredited CA has a public key signed by the accreditation body of Australia. The process of signing provides security to users that the CA is accredited. As long as users trust the accreditation authoritity, they will recognize each accredited CA as trusted. This model is similar to the concept of the strict hierarchy model. However, each accredited CA may have its own unique CP and CPS and nothing prevents them from having only a signed public key which is not allowed in the model of strict hierarchy.

Analysis of the Existing PKI Interoperability Models

Each of the above mentioned models of interoperability has its good and bad sides. Not all models can solve the problem of the interoperability of already established PKIs. Such models require that interoperability be

designed first, and then PKI architecture be established. Some models are rigid because they enable only interoperability of CAs in the hierarchy, while others overcome this by establishing cross-relations of trust which complicate the processing of certification paths. Some models implement the policy only through the acceptance of contracts, while others can implement it through certificates. On the other hand, some models are not suitable for international interoperability.

In order to establish the most favorable model of trust for the establishment of interoperability, the models were evaluated from the point of scalability, processing of certification paths, application of policies, point of failure, re-establishment of trust and the possibility of establishing the interoperability of the existing with new national PKI domains and their connecting with international PKI domains.

The single CA model cannot be applied to solve interoperability problems because it would involve only one CA to issue certificates for all PKI users, and it is necessary to have at least two PKI domains in order to achieve interoperability. The introduction of this model of trust aimed at reducing the number of PKI domains in order to solve the interoperability is not a good solution because this model is not scalable. Furthermore, it is technically and administratively demanding at the state level and cannot meet all the requirements of users and organizations. A good feature of this model is a rapid discovery of a certification path and validation. Generally speaking, this model can achieve neither interoperability between the existing PKI domains and the new PKI domains nor their interoperability with international PKI domains.

The strict hierarchy model can be used to connect the existing PKI domains although this model connects multiple certification authorities. This model could have achieved the PKI interoperability in the PKI domain of R. Serbia before the existing PKI domains were formed, by forming a national root certification authority from which the existing and new PKI domains or subdomains would have stemmed. In this way, centralized policies would have been applied and certification paths would have been faster discovered and validated. However, as mentioned before, this model cannot be applied to connect the existing PKI domains, or for connecting with international PKI domains. The problem of this model is the security of the root CA because jeopardizing its security would cause failure of all PKIs in the state. The introduction of a centralized root CA separately for the government domain and separately for the commercial domain would enable faster discovering and validation of certification paths between PKI domains which would be connected by some other model.

The cross-certification model can be applied for the establishment of interoperability, but only between two or three PKI domains. Connecting multiple PKI domains represents a technical and administrative challenge; furthermore, it does not solve the problem of interoperability with international PKIs. Establishing more cross-certifications would lead to the problem of coordination of certification policies and to the problems in the process of discovering and validation of certification paths.

The cross-recognition model can be used to establish interoperability between the PKI domains in R. Serbia. The PKI domains would agree to mutually recognize the certification authorities before they build a technical solution. This requires a close cooperation between the PKIs or the existence of accreditation agencies, which currently is not the case (there is an organizational unit in the Ministry of Trade, Tourism and Telecommunications that works on the CA certification for entering the Register of Certification Authorities issuing qualified certificates). The recognition allows formal and reciprocal recognition of new PKI domains by the competent PKI authority (top trust point). Trust is achieved by accepting the standards, policies and processes for the acceptance of appropriate trust certificates in the identified fields. This way of trust enables the users of one PKI domain to rely on the certificates of another domain for use in specific applications within the accredited certification policy. This model can be used as a temporary solution for the formal interoperability of the existing PKI, until establishing a model that will enable the connection of all existing, new and international PKIs.

The certificate trust list model is a potential model for interoperability that could be applied. In order for users to trust the certification authorities in the trust list, it is necessary that each item in the list and the list itself are signed by a trusted authority in whom all users trust. The problems of this model are the growth of the trust list, non-existence of central administration and implementation of validation process within an organization, list update and its maintenance. The lack of scalability, the loss of central administration, policy enforcement and additional operating costs related to the access to the list reduce the use of this model for resolving the trust across multiple PKI domains in R. Serbia and the trust with international PKI domains.

The accreditation certificate model includes the introduction of an accreditation CA that will sign other CA certificates. In this way, users who believe the accreditation authority also believe the users from other PKI domain CAs to which the accreditation authority signed certificates. This model can create trust between the PKI domains in R. Serbia by forming the accreditation CA that would sign the keys of all root CAs thus achieving interoperability with the harmonization of policies and technical issues regarding discovering and validation of certification paths. Also, the accre-

ditation CA would sign a CA certificate to newly added PKI domains. This approach is possible because this model allows each accredited CA can have its own unique CP and CPS. In addition, nothing prevents the CA from having a self-signed public key. However, this model does not solve the problem of interoperability with international PKI domains.

The bridge model is designed with the aim of connecting multiple PKI domains. This model helps to centralize the management of interoperability problems in a single body that can develop and promote best practices. It allows the connection of different PKI architectures, including bridge architecture, so that all architectures merge into one thus enabling interoperability. The model is scalable because it allows adding both the existing and new PKIs, reduces the number of cross-certificates and makes it easier to discover and validate certification paths better than the mash model. In addition, policies can be implemented through certificates, connection with international PKIs is possible, and the bridge model failure does not affect internal operability within individual PKI domains. The problem may occur with a large number of PKI domains which complicates the process of discovering and validation of certification paths. This model is most acceptable for the establishment of interoperability between national PKIs in R. Serbia and their interoperability with international PKIs.

Proposed PKI Interoperability Model for the Republic of Serbia

There are six accredited certification authorities (governmental and non-governmental) which issue qualified certificates in R. Serbia or six PKI domains between which it is necessary to establish PKI interoperability. All certification authorities are based on a hierarchical PKI architecture with a root CA as the top point of trust and one or more subordinate CAs.

When choosing a model of interoperability, the following has been taken into consideration:

- processing certification paths, i.e. its discovery and validation from the end user to the point of trust,
- determining the properties of the certificate from certificate policy, and
- determining whether the certificate is trusted for the intended purpose.

This chapter gives a conceptual proposal of the multidomain PKI interoperability in R. Serbia, which includes the realization of the:

- interoperability between the existing accredited PKI domains,

- interoperability between newly established PKI domains in the governmental and public sectors, and
- interoperability of the PKI domains in R. Serbia with international PKI domains.

The proposed model of the interoperability of PKIs in R. Serbia, Figure 2, is based on the bridge model that enables interoperability between the existing (enrolled in the Register[1]) and new PKI domains of different architectures (hierarchicals, mashs, bridges) as well as their connection with international PKI domains. The basic model has been extended with the validation authority that allows faster processing of certification paths. As an integral part of the national PKI infrastructure, an accreditation body that determines the general certification policy of the PKI in R. Serbia is introduced. The introduction of an accreditation body is initiated by the fact that governmental and public PKIs have been established without a clear global policy on PKIs in R. Serbia. This model allows the implementation of a clear PKI policy for all PKI domains.

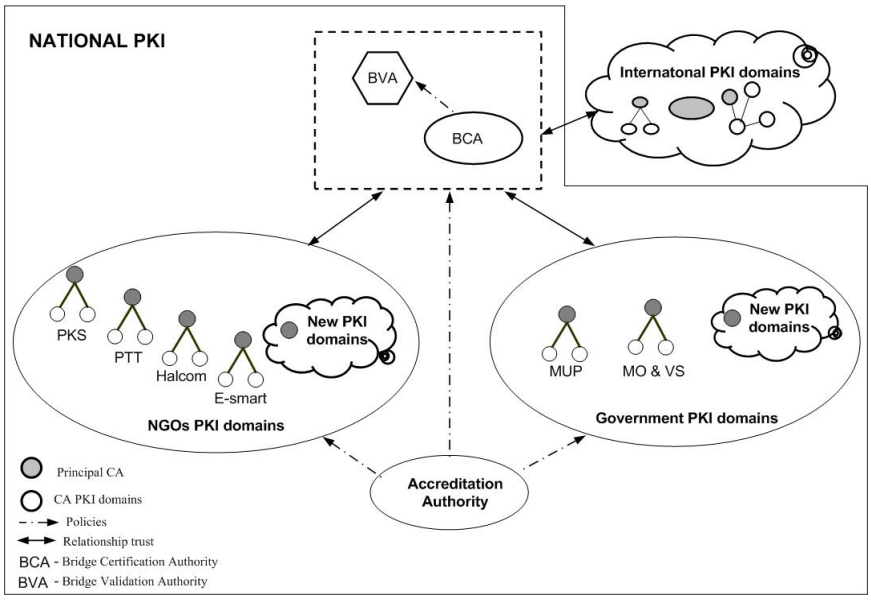

Figure 2 – The proposed model of PKI interoperabilty in the Republic of Serbia
Рис. 2 – Предлагаемая модель ПКИ взаимодействия и доверия в Республике Сербия
Слика 2 – Предложени модел PKI интероперабилности Републике Србије

[1] The Register of certification authorities for issuing electronic certificates, http://epotpis.mtt.gov.rs/elektronski-potpis/

This concept allows the connection of PKI domains which enable electronic business between citizens, the state, government administration, local administration and local government, businesses, health, culture and other scopes that require the safe exchange of distributed and security sensitive data.

The bridge PKI mode i.e. the bridge CA achieves relations of trust between different PKI domains. The trust is achieved by establishing peer-to-peer relations of trust with the CAs of different PKI domains. The trust with governmental and non-governmental root CAs is achieved via the existing PKI domains.

The policy of the bridge CA defines the interoperability mechanism to ensure trust over different PKI domains. A successful cross-certification confirms that an applying PKI operates in accordance with the standards, guidelines and practices of policy issued by the authority of interoperability. The Memorandum of Cross-Certification (formally describing the conditions of cross-certification) is signed between the bridge CA and an applying PKI.

One of the main advantages of using the bridge CA trust model is to provide centralized management and automated enforcement of a validation policy. The path of trust is built by cross-certification between PKI domains and the bridge CA. The policy of certificate validation may limit the scope of trust through the established cross-certification. The application of this policy to certificates at the time of transactions allows security and trust of business processes between PKI domains.

Validation policies include specific rules and parameters to be used during the validation of certificates. In this model, validation policies are implemented through the use of policy and (or) limitations specified in cross-certificates. Constraint policies are used to restrict the use of certificates based on the policies under which the certificate was issued.

When PKI domains enter the bridge interoperability model, in addition to the establishment of relations of trust and the acceptance of policies, a contract on the implemented validation policies is concluded. New PKI domains may limit the relations of trust with other PKI domains and their subdomains, as well as to exclude certain subdomains. This is done by specifying a list of names (i.e. X.500 characteristic names) of all subdomains in the "name constraint" extension of cross-certificates. There is an option to include or exclude specific names or subgroup names (for example, all of abc.gov addresses) via this mechanism.

The proposed model allows automated discovering and validation of certification paths, including the application of restrictions. The accepted validation policy is implemented in the extension of cross-certificate after

codification. In this way, an automatic validation process is enabled for all future transactions.

In the existing PKI trust models, a construction of the trust path is a simple process because they are all based on a hierarchical architecture. However, the process of discovering certification paths via the bridge CA becomes a complex process due to cross-certificates. The main problem is in the processing of certification paths which can be time-consuming for applications using PKI in their work. This problem could be solved by applying a protocol for simple certificate validation, named SCVP (Server-based Certificate Validation Protocol) (Freeman, et al, 2007).

The SCVP standard defines two accesses of delegating discovering the path of trust. In the first approach, Delegate Path Discovery, the client delegates the task of discovering the certification paths to the SCVP server, but not the task of its validation. In the second approach, Delegate Path Validation, the client delegates the task of constructiing a valid certification path and the task of validating, i.e. confirming that the public key contained in the certificate profile can be used for its purpose. Both approaches relieve the user application of the problem of discovering and validating certification paths through centralized validation policy.

A crucial factor in the development of any PKI is to achieve scalability to be able to meet the needs of more users. PKIs in R. Serbia are based on a hierarchical architecture, and considering that this type of arhitecture is scalable and the easiest to implement, it is expected to witness an increase in the number of PKI domains, users, and, consequently, certificates. An increased pressure from the state on all levels of government to use the services of e-government and e-commerce will result in a large number of transactions. This leads to a need to build validation systems because the authentication and verification of trust of paths, as a part of the confirmation of each transaction, must be automated, scalable and secure.

The system for discovering and validating certification paths of the proposed model has to satisfy the following requirements:

- High performance - the system has to provide quick answers to the application's request so that users do not notice that the validation process has started,
- High availability - the system must be available when the end user wants to use it,
- Scalable - increasing the number of users and PKI domains should have a minimal impact on performance, availability and security,

- Security - the system must ensure public confidence in the security of information exchanged in transactions using the certificate,
- Interoperable - a system must be based on open standards to ensure interoperability with all applications in accordance with appropriate standards,
- Low risk - the system must be based on technology that has been proven to work in realistic operational scenarios of equal or larger size.

The proposed model has the following advantages over the other models:

- Centralized management and automatic implementation of validation policy,
- Automation of processing certification paths of trust between domains, including the application of restrictions,
- Automatic validation process for all subsequent transactions without the need for any transaction, especially considering the terms of the contract,
- Expansion of the national PKI by new governmental and non-governmental PKI architectures is simple, it does not complicate the process of discovering certification paths and it is transparent to users,
- Breach of security of individual PKI domains does not affect the functionality of the entire national PKI,
- There are restrictions to the failure of the national PKI in the event of compromising one private key, since more keys of the bridge CA can be used to establish relations of trust.

Conclusion

PKI interoperability is necessary for the establishment of a national PKI in securing electronic services that use certificates on a national and global level. Depending on their advantages and disadvantages, the existing PKI interoperability models, can be used, to a greater or lesser extent, as standalone or in a combination with other models for the realization of PKI interoperability. When considering the introduction of PKI in the country, the need for interoperability should be addressed first, then the criteria should be established followed by the development of PKI interoperability policies. The proposed PKI interoperability model provides

a good basis for the improvement of the national PKI and for the connection with international PKIs.

Further research should be carried out in the direction of organizational solutions of the PKI interoperability in R. Serbia and concrete technical solutions arising from the proposed model, such as the mechanism for processing certification paths and software of the bridge certification authority.

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МОДЕЛЬ ДОВЕРИЯ И АРХЕТЕКТУРА
PKI В РЕСПУБЛИКЕ СЕРБИЯ

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ВИД СТАТЬИ: профессиональная статья
ЯЗЫК СТАТЬИ: английский

Резюме:

Применение электронного сервиса, использующего цифровые сертификаты увеличивается с каждым днем, увеличивается также и количество внедренных инфраструктур открытых ключей, в связи с чем появилось необходимость в их объединении и взаимодействии. В данной статье представлены результаты проведенного анализа модели взаимодействия между различными доменами инфраструктуры открытых ключей и возможность их применения в осуществлении взаимодействия инфраструктур открытых ключей в Республике Сербия.

Применение существующих моделей взаимодействия рассматривается с точки зрения масштабируемости, обработки сертификационного маршрута, применения политики, точки отказа и возможности установления новых доверительных отношений. Разработана концептуальная модель, основанная на мостовой модели доверия. Данная модель обеспечивает взаимодействие существующих и новых национальных PKI (Public Key Infrastructure) доменов их соединение, а также подключение к зарубежным PKI доменам. Модель

расширена валидационным авторитетом, который обеспечивает эффективную обработку сертификационного пути.

Ключевые слова: сертификат, PKI системы, домены, доверие, модели, инфраструктура.

МОДЕЛ ЗА PKI ИНТЕРОПЕРАБИЛНОСТ У РЕПУБЛИЦИ СРБИЈИ

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ОБЛАСТ: информационе технологије
ВРСТА ЧЛАНКА: стручни чланак
ЈЕЗИК ЧЛАНКА: енглески

Сажетак:

Све већа примена електронских сервиса који користе електронске сертификате и све више имплементираних инфраструктура јавних кључева условили су потребу за њиховим међусобним повезивањем, односно остваривањем интероперабилности. У овом раду извршена је анализа модела за интероперабилност између различитх домена инфраструктуре јавних кључева и њихова могућа примена у остваривању интероперабилности инфраструктура јавних кључева у Републици Србији. Примена постојећих модела интероперабилности сагледана је са аспекта скалабилности, обраде сертификационе стазе, примене политика, тачке отказа и могућности поновног успостављања поверења. Предложен је концептуални модел заснован на мостовном моделу поверења. Овај модел обезбеђује успоставу интероперабилности постојећих, нових националних PKI (Public Key Infrastructure) домена, њихово међусобно повезивање, као и повезивање са иностраним PKI доменима. Модел је проширен валидационим ауторитетом који обезбеђује ефикаснију обраду сертификационе стазе.

Кључне речи: сертификат, PKI системи, домени, интероперабилност, модели, инфраструктура.

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ПРИКАЗИ
ОБЗОРЫ
REVIEWS

19. МЕЂУНАРОДНА КОНФЕРЕНЦИЈА ICDQM-2016 (ПРИКАЗ ЗБОРНИКА РАДОВА)

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ОБЛАСТ: менаџмент, квалитет, поузданост, рачунарске науке, информационе технологије
ВРСТА ЧЛАНКА: приказ
ЈЕЗИК ЧЛАНКА: српски

Сажетак:

У овом приказу наводе се основне информације о укупним резултатима, значају, међународном програмском одбору и областима рада 19. међународне конференције „Управљање квалитетом и поузданошћу ICDQM-2016" и 7. међународне конференције „Управљање и инжењерство животног циклуса" (радови су на српском, енглеском и руском језику), која је одржана под истим називом ICDQM-2016. Представљени су број и структура радова обе конференције, по секцијама: војно инжењерство, инжењерство квалитета, инжењерство поузданости, индустријско инжењерство, системско инжењерство, енергетска ефикасност и економична производња, а приказани су само пленарни радови припадника Војске и Министарства одбране Републике Србије. На овој конференцији било је, до сада, највише објављених радова припадника Војске и Министарства одбране Републике Србије.

Кључне речи: квалитет, поузданост, војно инжењерство, конференција, приказ.

У Пријевору код Чачка, у Истраживачком DQM центру, од 29. до 30. јуна 2016. године, одржана је 19. DQM међународна конференција „Управљање квалитетом и поузданошћу ICDQM-2016" (19th International Conference Dependability and Quality Management ICQDM-2016) и,

истовремено, 7. међународна конференција „Управљање и инжењерство животног циклуса" (7th DQM International Conference Life Cycle Engineering and Management) ICQDM-2016).

Организатор конференције је, као и до сада, DQM истраживачки центар (Истраживачки центар за управљање квалитетом и поузданошћу) из Пријевора код Чачка, којим руководи проф. др Љубиша Папић.

Конференција, као и до сада, обухвата области: инжењерство квалитета, инжењерство поузданости, индустријско инжењерство, системско инжењерство, војно инжењерство, енергетска ефикасност и економична производња. До сада је у зборницима ове конференције публиковано 2290 радова.

Области ICDQM конференције веома су интересантне и значајне и за припаднике Војске Србије и Министарства одбране Републике Србије (МО), па на конференцији постоји и посебна област војно инжењерство (уведена као секција 2009. године), због значаја радова и континуитета учешћа припадника Војске и Министарства одбране.

Програмски одбор овогодишње 19. DQM конференције има 26 чланова из 10 земаља (БиХ 1, Велика Британија 1, Индија 2, Канада 1, Русија 3, САД 1, Србија 10, Шпанија 1, Чиле 1, Украјина 2) (ICDQM 2016 Позив). Програмски одбор овогодишње 7th DQM конференције има 32 члана из 13 земаља (Аустрија 1, БиХ 1, Велика Британија 1, Израел 5, Индија 6, Јордан 1. Русија 6, САД 1, Србија 4, Шведска 2, Шпанија 1, Холандија 1, Хрватска 2).

И ове године је Комисија програмског одбора, од радова саопштених на прошлогодишњој конференцији, прогласила два најбоља рада, један из области академских истраживања, а један из области примењених истраживања у привреди. Аутори оба рада су припадници Војске Србије:

1. „Развој концепције логистике Војске Србије" чији су аутори *Марко Андрејић*, *Марјан Миленков*, *Марјан Мирчевски* и *Слободан Панић* из Војне академије Универзитета одбране у Београду;

2. „Примена комбинације метода вишекритеријумске анализе код избора оптималне организације одржавања радио-релејних уређаја" чији су аутори *Војкан М. Радоњић*, *Слободан Р. Ђукић*, *Иван Милојевић* и *Данко М. Јовановић* из Техничког ремонтног завода „Чачак".

На конференцији је одржана изложба књига наставника и сарадника Катедре логистике на Војној академији, Универзитета одбране у Београду. О књигама је говорио пуковник проф. др *Марко Андрејић*, начелник катедре.

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Поред тога, одржана је и промоција пет нових књига из области поузданости и логистике, међу којима две књиге аутора из Војске Србије: „Информациони системи логистике", чији је аутор *Данко Јовановић*, и „Менаџмент техничком подршком", аутора *Марка Андрејића* и *Марјана Миленкова*. Обе књиге издао је Медија центар „Одбрана", Београд.

Такође, одржана је промоција четири часописа: један чији је уредник Љубиша Папић и излази у Србији и још три руска часописа у којима је Папић члан уређивачких одбора.

За конференцију су штампана два зборника радова, а постоје и на ЦД-има. У зборницима има укупно 148 радова (прошле године 160), аутора из 8 земаља (прошле године 7): Алжир, Босна и Херцеговина, Хрватска, Немачка, Русија, Србија, Шведска и Шпанија (ICDQM 2016, 19. DQM), (ICDQM 2016, 7th DQM), (Pokorni, 2016).

У зборнику радова „19. ДQM међународна конференција Управљање квалитетом и поузданошћу ICDQM-2016" (на српском језику) објављено је 99 радова (прошле године 120), и то 6 пленарних саопштења, 17 радова у секцији инжењерство квалитета (Quality Engineering), 7 у секцији инжењерство поузданости (Reliability Engineering), 25 у секцији индустријско инжењерство (Concurent Engineering), 8 у секцији инжењерство система (Systems Engineering), 30 у секцији војно инжењерство (прошле године 26), 3 у секцији енергетска ефикасност и 2 у секцији економична производња (Lean Production).

У зборнику радова „7th DQM International Conference Life Cycle Engineering and Management" (радови на енглеском и један рад на руском језику) објављено је 49 радова (прошле године 40), од чега 20 пленарних саопштења, 10 у секцији Quality Engineering, 4 у Reliability Engineering, 5 у Industrial Engineering, 4 у Systems Engineering и 6 у Military Engineering.

Званични језици конференције били су енглески, руски и српски.

Припадници Војске, односно Министарства одбране Србије, имају укупно 64 рада (прошле године 47), што је највише од почетка одржавања конференције. У табели 1 приказан је број радова припадника Војске Србије и МО и укупан број радова на конференцији, у последњих 7 година, од када постоји секција војно инжењерство (Pokorni, 2016). Ове године је број радова припадника Војске и МО у секцији војно инжењерство већи него у осталим секцијама (36 у односу на 28, табела 1).

Припадници Војске и МО нису имали радова на страном језику у пленарним излагањима, а у осталим секцијама имали су 11 радова на страним језицима (10 на енглеском и 1 на руском језику), табела 2.

Због великог броја радова припадника Војске и Министарства одбране Републике Србије, чије би представљање учинило овај приказ преобимним, наводимо укратко садржај само пленарних радова, редоследом како су приказани у зборнику радова, који је штампан пре одржавања конференције.

Табела 1 – Преглед броја радова припадника ВС и МО и укупног броја радова на ICDQM
Таблица 1 – Обзор количества работ представителей ВС и МО и общего количества работ, представленных на конференции ICDQM
Table 1 – Overview of the papers of the Serbian Army and MoD members and the overall number of papers at the ICDQM

	Година							
	2016.	2015.	2014.	2013.	2012.	2011.	2010.	2009.
Секција војно инжењерство	36	28	22	9	6	6	18	12
Остале секције	28	19	20	21	10	8	10	2
Укупно ВС и МО	64	47	42	30	16	14	28	14
Укупно ICDQM	148	160	160	180	155	141	162	148

На нивоу пленарних предавања публикована су два рада припадника МО, на српском језику, оба рада аутора са Војне академије Универзитета одбране:

Данко Јовановић, Универзитет одбране, Војна академија, Београд

Могућност привредне сарадње Републике Србије и Републике Српске

У раду се анализирају резултати студије „Сличности и комплементарности привредне структуре Републике Србије и Републике Српске као основа економске сарадње". Аутор наводи да је студија рађена у сарадњи Министарства регионалног развоја и локалне самоуправе Републике Србије и Економског института Бања Лука, да је завршена 2014. године, да представља аналитичку платформу за припрему и реализацију усвојеног Пројекта „Подриње", те да је циљ тог пројекта интегрисани економски и социјални развој регије Подриње, кроз заједничке иницијативе на међувладином, регионалном и локалном нивоу, а да је протокол у вези овог пројекта,

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између Владе Републике Србије и Владе Републике Српске потписан 2. октобра 2012. године. Основни циљ студије је утврђивање привредне позиције са тежиштем на кључним аспектима спољнотрговинске економије Републике Србије и Републике Српске, те проналажење кључних утицаја на извоз и увоз, као и утврђивање могућности повећања међусобне робне размене.

Табела 2 – Преглед броја радова припадника ВС и МО по секцијама
Таблица 2 – Обзор количества работ представителей ВС и МО по секциям
Table 2 – Overview of the papers of the Serbian Army and MoD members in conference topics

СЕКЦИЈА	Радови на језику			Укупно
	српски	енглески	руски	
Пленарна саопштења	2			2
Инжењерство квалитета	6	1		7
Инжењерство поузданости	4	4		8
Индустријско инжењерство	6			6
Системско инжењерство	1			1
Енергетска ефикасност	2			2
Економична производња	1			1
Допунска саопштења	1			1
Војно инжењерство	30	5	1	36
УКУПНО	53	10	1	64

Марко Андрејић, Марјан Миленков, Универзитет одбране, Војна академија, Београд

Концепт и приступ стварању квалитетних официра за потребе логистике одбране

У резимеу овог рада аутори констатују да стварање и развој официра за потребе логистике одбране треба да се заснива на стратешком оквиру за одбрамбено промишљање, захтевима војске и војне професије, организацији и технологији високог образовања и војног оспособљавања. У тражењу квалитетних решења усмерених на стварање квалитетног кадра треба се оријентисати на његов животни циклус, ток кретања у простору и времену и на квалитет услуге образовања и васпитања којим се он ствара. Поред тога, идеја водиља треба да буде школовање кадра за запошљавање, а не за конкретно радно место. При пројектовању профила логистичког кадра и специфицирања захтева неопходно је идентификовати захтеве бројних

радних места, кориснике услуга и производа логистике и друге важне стејкхолдере и уважити препоруке и захтеве носиоца развоја логистичког кадра, образовних и научних установа. Стварањем логистичког кадра, кроз процес образовања и васпитања, достижу се одређене способности, формирају ставови, стичу одређена знања, вештине и навике и јачају све три компоненте војне професије: физичка, интелектуална, и морална. Пракса налаже да се одређене парадигме везане за процес стварања и развоја логистичког кадра морају, постепено, критички анализирати и мењати, идући у сусрет будућој стварности и догађајима.

На крају, може се констатовати да овогодишња конференција има мањи укупан број радова него претходна, али припадници Војске и Министарства одбране Републике Србије имају највећи број радова до сада (табела 1). Њихов удео радова на овогодишњој конференцији је више од 43% укупног броја радова, а имају радове у свим секцијама конференције, што указује на широк спектар области којима се баве.

Наставља се тренд сарадње аутора из разних институција Војске и МО Србије међусобно и са институцијама ван Војске. Већина радова је колективно дело више аутора. Међутим, неколико истих аутора јавља се на више од 3 рада (на већини научних скупова је ограничено да се исти аутор може појавити на највише 2 рада, а на некима 3).

Као и претходних година, на конференцији су учествовали некадашњи припадници Војске, који сада раде у високообразовним институцијама у цивилству.

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19-АЯ МЕЖДУНАРОДНАЯ КОНФЕРЕНЦИЯ ICDQM-2016
(ОБЗОР СБОРНИКА СТАТЕЙ)

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ОБЛАСТЬ: менеджмент, качество, надежность, компьютерные науки, информационные технологии
ВИД СТАТЬИ: обзор
ЯЗЫК СТАТЬИ: сербский

Резюме:

Данный обзор включает основную информацию о результатах работы и значимости 19-ой Международной конференции "Управление качеством и надежностью" – ICDQM-2016 и 7-ой Международной конференции «Программная инженерия и управление этапами жизненного цикла» (доклады на сербском, английском и руском языках), которая была проведена под одноименным названием «ICDQM-2016». В обзоре приведены: количество и структура докладов, зачитанных на конференциях, распределенных по следующим секциям: военная инженерия, инженерия качества, инженерия надежности, промышленная инженерия, системная инженерия, энергоэффективность и бережливое производство, но рассматриваются исключительно пленарные статьи, авторами которых являются военнослужащие, представители Министерства Обороны Республики Сербия. Настоящий сборник является ведущим по количеству опубликованных статей, авторами которых являются военнослужащие, представители Министерства Обороны Республики Сербия.

Ключевые слова: качество, надежность, военно-инженерое дело, конференция, обзор.

19TH INTERNATIONAL CONFERENCE ON DEPENDABILITY AND QUALITY MANAGEMENT ICDQM-2016 (REVIEW OF THE PROCEEDINGS)

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FIELD: Management, Quality, Reliability, Computer Sciences, Information Technology
ARTICLE TYPE: Review
ARTICLE LANGUAGE: Serbian

Summary:

The article presents the basic information about the overal results, significance, international programme committee and working areas of the 19th DQM International Conference on Dependability and Quality Management ICDQM 2016 and 7th DQM International Conference on Life Cycle Engineering and Management (papers printed in Serbian, English and Russian), which was held under the same acronym ICDQM-2016. The number and structure of papers of both conferences are given in Sections: Military Engineering, Quality Engineering, Reliability Engineering, Industrial Engineering, Systems Engineering, Energy Efficiency and Lean Production. Only the plenary papers presented by the participants from the Armed forces and the Ministry of Defense of the Republic of Serbia are reviewed. This year's conference has been the best so far regarding the number of papers from participants from the Armed forces and the Ministry of Defense of the Republic of Serbia.
Key words: quality, reliability, military engineering, conference, review.

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Модернизација индијских сухоја 30[1]

Последњих неколико месеци појавиле су се индиције да ће доћи до убрзања програма модернизације индијске флоте авиона Su-30MKI. Индијско ратно ваздухопловство поручило је 272 авиона од којих је Русија, у периоду од 2002. до 2007. године, испоручила 50 летелица. Предвиђено је да остатак од 222 ловца произведе индијска корпорација HAL у чијим је постројењима 2004. године и започета производња на основу руске лиценце. До сада је произведено више од 200 авиона, а ловац Su-30MKI је најзаступљенија вишенаменска летелица у употреби индијског ратног ваздухопловства.

Ловац Su-30MKI

Иако је Su-30MKI један од најмодернијих ловаца генерације 4+ у служби индијског ратног ваздухопловства, потреба за модернизацијом је све већа. Први авиони испоручени су Индији још 2004. године. Од тада су многе нове технологије постале доступне у Русији, Индији и другим тржиштима, укључујући нове радаре, нове ракете и бомбе. Иначе, платформа Su-30 је врло погодна за све врсте модернизација, од конзервативне до радикалне, с обзиром на то да овај авион има кокпит предвиђен за два члана посаде, а могуће је сместити много кабасте и тешке опреме.

[1] The National Interest 31 August 2016

О модернизацији Su-30MKI дуго се ништа није знало, сем да се ради о програму *Sukhoi Super 30*, Није било никаквих информација у вези с техничким спецификацијама, временским роковима или трошковима. Војни коментатори често су мешали програм *Sukhoi Super 30* са неким другим програмима чији је циљ била интеграција противбродске крстареће ракете *BrahMos*. Ова противбродска ракета биће инсталирана на 40 до 42 авиона, а тај програм није у вези са програмом *Sukhoi Super* 30. Програм интеграције ракете *BrahMos* налази се у поодмаклој фази и већ су урађена тестирања на авиону Su-30MKI на којем су извршена ојачања авионске конструкције. Програм *Sukhoi Super* 30 обухвата целокупну индијску флоту авиона Su-30MKI, још није започет и до недавно није било скоро никаквих информација.

Недавно је утицајни индијски лист „*The Hindu*" пренео информацију да су током јула 2016. године Русија и Индија одржале консултације у вези с поменутим програмом, а да се потписивање уговора очекује у блиској будућности. Други, добро информисани лист „*The Economic Times*", известио је да ће технички захтеви у вези с програмом бити закључени до краја године и да ће уговор бити потписан почетком 2017. године. Очекује се да ће трошкови програма износити између 7 и 8 милијарди долара, а једна од његових основних карактеристика биће учешће локалних снабдевача као дела нове индустријске политике индијске владе.

Специфичности индијске политике набавки

Оригинални програм Su-30MKI био је, за индијске прилике, урађен врло брзо. Са друге стране, програм модернизације кретао се изузетно споро, што представља нормалну брзину развоја програма у индијском систему одбране. Након што је Русија представила првобитни предлог за набавку ловца Su-30MKI прошло је само три године од потписивања првог уговора. Предлог је понуђен у децембру 1993. године, а уговор је потписан у новембру 1996. године. Прве техничке спецификације ловца Su-30MKI доста су се разликовале од спецификација за ловца Su-30K који је Русија првобитно планирала да прода Индији. Нису се разликовали само авионски инструменти већ и сама конструкција авиона.

Програм ловца Su-30MKI и даље је непревазиђен по питању времена имплементације. Већина програма индијске аеронаутичке индустрије се веома споро реализује, а пример представљају модернизације ловаца *Mirage* 2000 и MiG-29. Модернизације представљају најбољи и најјефтинији начин побољшања способности индијског ратног ваздухопловства с обзиром на постојећа ограничења и парализу тендерских процедура које су онемогућиле Индију да повећа број ескадрила ратног ваздухопловства на 45.

Почетком двехиљадитих година индијско ратно ваздухопловство било је у потпуној надмоћи у односу на пакистанско по сваком основу, а технолошки супериорно у односу на кинеско ратно ваздухопловство, што је поништило бројчану предност Кине. Оваква надмоћ остварена је великим делом захваљујући брзој имплементацији програма Su-30MKI. Након тога,

постојећа равнотежа војне силе и технологије није захтевала брзу набавку нових авиона нити модернизацију постојећих.

Међутим, сада се ситуација потпуно променила. Пакистан је добио нове верзије америчких ловаца F-16 и неколико десетина кинеско-пакистанских авиона FC-1. Док је Индија, током двехиљадитих година, остваривала потпуну доминацију над пакистанским ратним ваздухопловством, сада поседује тек незнатну супериорност. Врло је могуће да ће Пакистан изједначити број авиона са Индијом када добије наручене кинеске ловце J-10 (као и ловце J-31, пету генерацију ловаца). Овакво изједначење било би потпуно неочекивано.

Баланс снага у односу на кинеско ратно ваздухопловство представља још већи проблем за Индију. Током деведесетих година и почетком двехиљадитих, Кина је купила 76 ловаца Su-27SK/UBK и 100 Su-30MKK/MK2 од Русије. Убрзо је произвела још 105 ловаца Su-27SK на основу руске лиценце, а затим започела производњу клонираних авиона без икакве лиценце. Ови авиони садрже технологију из осамдесетих година, али је Кина тек од недавно почела да добија најновије руске ловце Su-35, а упоредо ради и на својој петој генерацији ловаца, што ће јој омогућити да достигне индијско ратно ваздухопловство у погледу технологије, док ће и даље задржати своју импресивну нумеричку супериорност. У том контексту постојећи индијски модел набавки за министарство одбране, који предвиђа седам до десет година само за припрему уговора, постаје потпуно застарео и неодржив.

Постоји све хитнија потреба за убрзавањем програма Su-30MKI који би обновио технолошку супериорност индијског ратног ваздухопловства над кинеским. Индија мора да понови исту операцију када је, током деведесетих година, покренула првобитни програм набавке ловца Su-30MKI, као одговор на масовну кинеску набавку ловаца Su-27/30. Сада Индија мора одговорити на кинеску набавку ловаца Su-35 и J-31 својим програмом модернизације Sukhoi Super 30.

Опције модернизације

Избор опција у оквиру модернизације састојаће се од компромиса између цене, времена и могућности модернизоване летелице. Теоријски посматрано, ради се о великом броју разних технолошких солуција. Конзервативно решење које би било најјефтиније и најбрже подразумевало би инсталирање свих технолошких решења која су уграђена на најновије верзије Su-30. Авион Su-30MKI представља најстарију верзију ове летелице у које спадају малезијски Su-30MKM (модел 2007) и руски Su-30SM (модел из 2011. године). Конзервативна модернизација подразумевала би ограничен број додатних одбрамбених система (слично малезијском моделу авиона), али и могућност коришћења нових ракета и паметних бомби које се сада развијају у Русији за ловац Su-30SM. Оваква модернизација довела би индијски ловац Su-30MKI на ниво Su-30SM.

Са друге стране, радикална модернизација довела би до развоја авиона на ниво америчког ловца F-15 *Silent Eagle.* Ова опција укључила би замену свих авионских система, а најважнија замена односила би се на радар. Пасивни радар са фазном решетком (PESA) био би замењен активним радаром са електронским скенирањем (AESA). Даље промене односиле би се на измену конструкције авиона ради смањења радарског одраза. Ова опција модернизације подразумевала би велике трошкове и време потребно за имплементацију.

Можда би најбоља опција била она која би укључивала надоградњу авионског радара N-011M *Bars* и интеграцију најновијих руских и индијских електронских, оптичких и инфрацрвених система без модификације авионске конструкције. Оваква модернизација била би оптимална у смислу унапређења авиона уз релативно скромна новчана улагања и кратку временску реализацију.

Разматра се могућност имплементације програма модернизације ловца Su-30MKI у неколико транши од по 50 до 55 авиона с тим да би свака серија подразумевала инкорпорацију све сложеније технологије. Овакав приступ предложио је *Yuri Beliy*, шеф компаније *NIIP Tikhomirov* која је пројектовала радар Bars. Beliy је у интервјуу изјавио да би се прва фаза модернизације састојала у унапређењу радара ради постизања већег домета, веће резолуције, веће отпорности на електронско ометање и омогућавања подршке за нове оружне системе. У каснијим фазама овај радар могао би бити опремљен активном фазираном решетком.

Овакав приступ омогућио би брзо покретање програма, довео би до унапређења способности индијског ратног ваздухопловства и олакшао би преобуку индијским пилотима. Оваква фазна стратегија је добро функционисала током периода 2002–2004. када је Русија испоручила прву серију од 32 авиона Su-30MKI. Ловци су испоручени у три групе од по 10, 12 и 10 авиона. Свака следећа партија укључивала је нова унапређења која су касније убацивана у претходно испоручене групе, па су на крају сва 32 ловца преведена на исти стандард.

Када су први пут изведене спецификације за Su-30MKI, индијско министарство одбране поднело је изузетно добро балансиране захтеве које је нови авион требало да задовољи .Они су представљали сам технолошки врх, које је руска индустрија могла спроведе по прихватљивој цени и у разумним временским роковима. Било би добро ако би се пронашло слично решење за програм Sukhoi Super 30.

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Опасно окружење за тенкове[2]

Заштита оклопних возила на бојишту никада није била толико важна као што је данас с обзиром на све већи број напредних, вођених противтенковских ракета великог домета.

Иако је модеран оклоп врло ефикасан, оклопна заштита је све више лимитирана ограничењима везаним са тежином возила с обзиром на то да је много лакше повећати убојност кумулативне бојеве главе него константно повећавати оклоп и тежину модерних оклопних возила. Данас је све већи број модерних тенкова, као што су израелски Merkava, амерички M1A1 Abrams и руски T-90, који су у недавним конфликтима озбиљно оштећени или уништени противтенковским ракетама и пројектилима.

На основу тога неопходно је наћи начин за пресретање противтенковских вођених ракета или ракета са ручних бацача опремљених кумулативном бојевом главом пре него што ударе по оклопним возилима. Активни системи заштите (hard kill) служе управо за то. Ови системи често су упарени или појачани системима заштите (soft kill) чија је улога упозорење, ометање или неки други начин превенције долажење претње. Иако постоје различите врсте активних система заштите (hard kill), већина њих потпада под две категорије: експлозивни панели и пресретачи.

Дејство активног система заштите

[2] Jane's Defence Weekly 7 September 2016

Активни системи заштите путем пресретача укључују *Afganit* (Русија), *Akkor* (Турска) и Land Electronic Defence System (Јужна Африка). Ови системи испаљују пресретач из лансера који се налази на возилу, пресретач пресреће долазећу претњу на одређеној даљини и онеспособљава га путем експлозивне фрагментације или самом експлозијом бојеве главе пресретача. С обзиром на то да пресретачи погађају циљ на одређеној раздаљини, ослањају се на податке добијене од радарских сензора. Пресретачки системи могу онеспособити циљеве на даљинама од преко 10 метара од заштићеног возила.

Експлозивни панели обично су монтирани на заштићеном возилу. Они детонирају пре него што непријатељев пројектил удари возило и онеспособљавају га путем експлозије, фрагментације или експлозивно формираног пројектила. Примери експлозивних панела постоје на следећим системима: израелски Trophy и немачки AMAP-ADS, али постоје и други. С обзиром на то да се реакција ових система очекује близу заштићеног возила, многи системи експлозивних панела употребљавају податке добијене од ласерских или других електрооптичких сензора који су често упарени са радаром на возилу.

Без обзира на тип активних система заштите, врло кратко време интервенције подразумева да ови системи морају радити у аутоматском режиму без уплитања посаде.

Израел

Израелски систем активне заштите Trophy, такође познат као ASPRO-A или *Me'il Ruach* (ветровка), за сада је једини стандардизовани систем активне заштите и један од два система који су прошли борбено крштење.

Систем *Trophy* обухвата четири радара *Elta* EL/M-2133 *WindGuard* ELM 2143, који су распоређени у кругу од 360 степени око заштићеног возила, централну контролну јединицу и два лансера. Сваки лансер садржи по једну плочу коју је могуће ротирати по азимуту и висини. Сама плоча развија ефекат неколико експлозивно формираних пројектила, а сваки лансер има неколико плоча ради поновног пуњења. Оваква конфигурација носи назив *Trophy-HV* и има масу од 850 кг.

Израелци су током 2006. године, приликом напада на милитантну групу Хамас у Гази, први пут доживели велике губитке; помиње се чак неколико десетина уништених или оштећених тенкова *Merkava*. Израелски тенкови сачекивани су и погађани модерним руским противтенковским навођеним ракетама са добро маскираних и утврђених положаја. Губици су били и у људству. Много израелских војника је рањено или погинуло. Одмах након тога израелске оружане снаге кренуле су са развојем и опремањем тенкова активним системима заштите.

Систем *Trophy-HV* налази се у оперативној употреби на тенковима *Merkava IV* од 2009. године, а први пут је употребљен у одбрани тенкова 2011. године. Систем је у великој мери коришћен и током израелског упада у Газу током 2014. године, а Израелци тврде да је био 100 посто успешан.

Наводно је велики број израелских тенкова био гађан противтенковским навођеним ракетама, али и ручним ракетним бацачима и ниједан није био ни оштећен. Наводи се да је на један тенк дејствовано са чак по 12 противтенковских ракета. Поред тога, систем *Trophy-HV* од радара добија и прослеђује посади тенка информацију о локацији са које је тенк гађан, што омогућава врло брзу повратну паљбу. Ову информацију могуће је пренети и на друга возила која су опремљена овим системом.

Израелска компанија *Rafael* наставила је са усавршавањем система *Trophy* и сада се очекује да ће овај систем бити инсталиран на ново израелско тешко оклопно возило пешадије *Namer,* а и на нови оклопни транспортер точкаш *Eitan* у конфигурацији 8x8. За сада овај систем нема прођу на извозном тржишту, иако је један од неколико које разматра аустралијска војска.

Израелско тешко оклопно возило пешадије Namer са системом активне заштите Trophy-HV

Компанија *Rafael* такође рекламира и други систем активне заштите под називом *Trophy LV,* који осим назива нема ништа заједничко са претходно описаним системом. За разлику од система *Trophy-HV*, *Trophy LV* је монтиран у кутијама које се налазе дуж крова возила. Електрооптички сензори откривају надолазећу претњу, детонирају експлозивни панел који испаљује, односно формира „енергетско сечиво" усмерено надоле према долазећој претњи.

Осим компаније *Rafael,* израелска војна индустрија израдила је свој систем активне одбране *Iron Fist*. Овај систем је пресретачког типа и обично се састоји од два усмеравајућа лансера од којих сваки покрива

поље од 270 степени. Сваки лансер садржи две пресретачке цеви, као и електрооптички ометач као алтернативан начин онеспособљавања претње (soft kill). Сами пресретачи су невођени и детонирају се даљинским путем помоћу радио-таласа када се налазе близу свог циља. Детонација уништава или онеспособљава циљ путем експлозивног ефекта, а не путем експлозивне фрагментације као неки други системи активне одбране. Оваква врста детонације умањује могућност детонације долазеће бојеве главе, а ефикаснија је у ситуацији одбране од кинетичког пенетратора који, експлозијом, скреће са путање ка брањеном возилу.

Систем Iron Fist развијен је као ривал систему *Trophy* и користи исти радар *Elta,* али је изгубио у надметању за опремање тенка *Merkava IV*. Са друге стране, израелска војска је одабрала систем *Trophy* за заштиту тешког оклопног транспортера *Namer,* док је америчка војска одабрала систем *Iron Fist* као заштиту возилу у оквиру програма Modular Active Protection Systems (MAPS), што представља велики извозни успех Израела и велику промену у ставовима америчке војске која до сада није имала систем активне заштите на својим оклопним возилима.

Русија

Русија је прва држава која је увела у оперативну употребу систем за активну заштиту (hard kill) у облику система *Drozd* на својим тенковима
Т-55АD који су били коришћени у сукобу у Авганистану. Овај систем био је монтиран на куполама тенкова са лансирним цевима за осам невођених пресретача формираних у паровима на странама куполе за покривање фронталног сектора у радијусу од 60 степени. Пресретачи су били невођени, 105 мм у дијаметру, и ослањали су се на фрагментациони ефекат приликом пресретања надолазеће претње. Иако су, по неким извештајима, били ефикасни, пружали су висок ризик колатералне штете пријатељским снагама или цивилима који би се нашли у близини. Систем су контролисали радари, док је укупна маса система била око 1.000 кг.

Иако су били релативно успешни приликом примене у Авганистану, Русија је поставила ове системе на веома мали број тенкова Т-55. Накнадно је развијен систем *Arena* који је лансирао експлозивно-формирајуће пројектиле са крова возила надоле према надолазећој претњи. Овакав метод значајно редукује колатералну штету, али *Arena* није уведена у оперативну употребу у руским оружаним снагама. Русија је након тога представила свој систем *Shtora* (soft kill) који се ослања на детекторе који упозоравају на надолазећу претњу и инфрацрвене лампе које служе за ометање система навођења противтенковских ракета. Систем *Shtora* налази се у употреби на руским тенковима Т-90 и Т-80, на алжирским тенковима Т-90, док се сличан систем заштите налази и на малом броју тајландских и украјинских тенкова Т-84 Oplot.

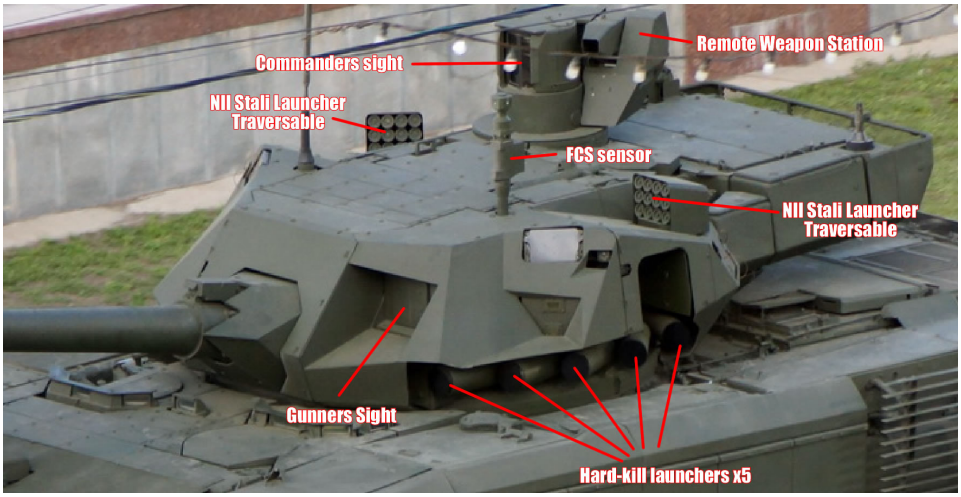
Систем активне заштите Drozd на тенковима T-55AD

Систем *Shtora* доживео је ватрено крштење у Сирији. Сиријски тенк Т-90 погођен је америчком противтенковском ракетом типа *Tow* (класична верзија без тандем бојеве главе), а након експлозије ракете на фронталном делу куполе, одмах код ометајућих инфрацрвених лампи, није дошло до секундарних експлозија које су карактеристичне за руске тенкове са аутоматским пуњачем. Прве реакције посматрача говориле су да се систем *Shtora* показао неделотворним. Међутим, нешто касније на интернету су се појавиле слике погођеног тенка где се јасно види површинско оштећење на предњем делу куполе након експлозије реактивног оклопа (старије генерације у односу на оклоп новог тенка Т-14 под називом Relikt 5). Наиме, плоча са реактивним оклопом пореметила је и ослабила сноп кумулативног пуњења ракете. Накнадно су објављени коментари поводом деловања/неделовања система *Shtora* са шпекулацијама да систем није скренуо ракету са своје путање, јер су поклопци куполе на тенку били отворени (ради брже евакуације сиријске посаде), што је онемогућило правилно функционисање система. Снимак поготка тенка показује да је горњи отвор на куполи био отворен и да је кроз њега искочио један сиријски војник, члан посаде, одмах након експлозије. Након првих, чини се нетачних коментара, појавили су се други коментари који су навели да систем *Shtora* није ни могао деловати, јер је тенк био гађан америчком противтенковском ракетом старије генерације Tow без ласерског навођења, па систем *Shtora* није ни могао ометати непостојећи ласерски сноп.

Руски тенк Т 90 погођен америчком ракетом старије генерације Tow

Русија се након развијања система *Drozd* окренула ка другим технологијама активне заштите. У мају 2015. године, током војне параде поводом дана победе, Русија је приказала нови тенк Т-14 *Armata* са одбрамбеним системом *Afganit*. Нови тенк опремљен је са 10 лансера пресретача који су монтирани на тенковској куполи у низу који покрива фронтални радијус од 120 степени и радарима AESA који раде на милиметарском таласу. Ови лансери изгледају слично пресретачима система *Drozd* у калибру 105 мм, а чини се да се ослањају на исти фрагментациони ефекат. Тенк Т-14 такође је опремљен додатним системом заштите (soft kil) у виду низа бацача граната. Оног тренутка када радари виде претњу, они преко система активне заштите одмах окрећу куполу тенка у том правцу и лансирају пресретаче. Осим система активне заштите hard kill, тенк Т-14 је опремљен и системом soft kill којим се испаљују димне гранате пуњене мултиспектралним димом ради маскирања возила од оператора противтенковских вођених ракета. Маскирање се врши ради умањења инфрацрвеног одраза и блокирања ласерског вођења ракета. Системи активне заштите типа *Afganit* присутни су и на оклопним возилима Т-15, *Kurganets-25* и *Boomerang*. Уколико ови системи заштите буду уграђени на већи број возила, Русија би била прва земља која би

увела системе активне заштите (hard kill) на сва оклопна возила тешке и средње категорије. Увођење система *Afganit* представљало је и крај развоја система *Arena*.



Распоред елемената система Afganit на тенку Т 14

Током 2016. године систем *Afganit* је тестиран приликом пресретања противтенковског пројектила са пенетратором од осиромашеног уранијума који лети брзином од 1,5 до 2 км у секунди, а судећи према руским изворима, пресретање је било успешно. Западни извори су скептични и наводе да је питање да ли су извештаји тачни, објашњавајући да је готово немогуће уништити пенетратор од осиромашеног уранијума путем фрагментационе експлозије, али дозвољавају могућност да га је тим путем могуће скренути са његове путање. Уколико би, опет, ови извештаји били тачни, то би означило револуцију у погледу заштите не само тенкова већ и других оклопних борбених возила. Русија, иначе, планира опремање овим системом активне заштите, не само тенкова Т-14 већ и тешког оклопног транспортера Т-15, али и других оклопних борбених возила.

Државе Запада

Европске земље, као и Сједињене Државе, оклевале су са увођењем система активне заштите. До данас ниједна европска држава, осим Русије, није поставила ниједан систем активне заштите на своја возила. То не значи да је европска одбрамбена индустрија била неактивна, што показује развој неколико различитих система активне одбране.

Најуспешнијом се показала немачка компанија *ADS Gesellschaft Fur aktive Schutzsysteme* са својим системом Advanced Modular Armor Protection – Active Defence System (AMAP-ADS). Систем није уведен у наоружање немачких оружаних снага, али је компанија објавила да је добила посао

серијске производње за „једну азијску државу”. Иако се званично не зна о којој се држави ради, верује се да је реч о Сингапуру, мада је и даље нејасно на које ће возило систем (AMAP-ADS) бити уграђен. Претпоставља се да ће бити монтиран на теренско возило Bronco, као и на сингапурски тенк *Leopard 2* SG.

Систем AMAP-ADS има директну паљбу, а ослања се на велики број сензора и противмера који се налазе око возила. За разлику од система Trophy HV, немачки систем активне заштите нема покретних делова и сличнији је израелском систему *Trophy LV*. Немачки AMAP-ADS приказан је као кровни систем (за мања теренска возила), а његови сензори и противмере директно су интегрисани у оклоп возила када су у питању већа возила као што су тенкови, борбена возила пешадије, гусеничари, као и точкаши у конфигурацији 8x8. Детекцију и систем за управљање ватром омогућавају сензори, док је сам систем уништавања AMAP-ADS описан као „директна енергија”, што умањује колатералну штету.

Активни систем заштите AMAP-ADS на борбеном возилу Fuchs

Растреситост система AMAP-ADS омогућава малу масу од само 145 кг, која се повећава до 500 кг на већим возилима као што су тенкови. Дистрибуција великог броја сензора и противмера око возила такође обезбеђује елемент редундандности, иако је утрошене противмере потребно ручно допуњавати. Овај систем користи се као основа система *Shark* који је

тестиран на француском оклопном возилу VAB 4x4, иако Француска није поручила коначну верзију система.

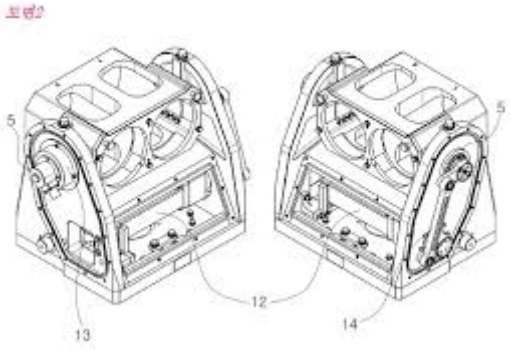
Немачка компанија *Diehl BGT* такође је развила активни систем заштите под називом Defence Active Vehicle Protection System. За разлику од система AMAP-ADS, то је систем заснован на пресретачима који се лансирају са управљивих лансера.

Овај систем има масу од 350 кг (један лансер), док се маса са два лансера повећава на 500 кг. Лансери имају три или четири цеви. Гранате су, наводно, ефикасне против противтенковских вођених ракета, али и кинетичких пројектила и онеспособљавају долазеће претње путем експлозивног, а не фрагментационог ефекта. Defence Active Vehicle Protection System напада циљеве на раздаљинама преко 10 м, што омогућава формирање безбедне дистанце од возила с обзиром на то да ефикасност кумулативних пуњења нагло опада на раздаљинама већим од неколико метара. Ефекат експлозије скреће са путање и кинетичке пројектиле.

Немачка за сада није узела у разматрање овај систем, већ је одлучила да употреби систем Multi functional Self protection System (MUSS) компаније *Krauss Maffei Wegmann* за борбено возило пешадије *Puma*. MUSS спада у системе активне заштите (soft kill) и користи инфрацрвени ометач и бацаче димних граната за заштиту возила. Велика Британија такође разматра овај систем. Постоји могућност да ће компанија развити и систем активне заштите (hard kill) као допуну и надоградњу.

Постоји још неколико система активне заштите који су развијени у Европи, али нису у употреби као што су украјински *Zaslon,* италијански *Scudo* и чешки *Aktivni Ochrana*.

Турска је, такође, инвестирала у технологије активних система заштите и тренутно ради на развоју свог система *Akkor* који спада у типичне пресретачке системе и укључује два двострука лансера и четири радарска панела који покривају радијус од 360 степени. Претпоставља се да ће бојеве главе пресретача онеспособљавати циљеве по основу експлозивног, а не фрагментационог ефекта. Пресретачке бојеве главе спадају у „паметне" због употребе програмабилних упаљача. Систем укључује и елементе (soft kill) који су засновани на ласерским сензорима и бацачима димних ракета. Развој овог система текао је упоредо са развојем турског тенка *Altay,* па се очекује да ће бити монтиран на њему, као и на оклопно возило средње класе *Arma* 6x6.



Турски систем активне заштите Akkor

Азија

Многе земље у Азији настављају са истраживањем на пољу активних система одбране за своја возила. Предњачи Јужна Кореја и њихов систем KAPS развијен за тенк *K2 Black Panther*.

Јужнокорејски систем KAPS на тенку K2 Black Panther

Први снимци дефинишу KAPS као пресретачки систем који се састоји од два покретљива лансера са по две лансирне цеви од 70 мм. Лансери су спрегнути са комплетом радара независним од система за управљање ва-

тром и радара за упозоравање који се налазе на предњој страни куполе K2. По томе је KAPS одвојен од напредног активног система одбране (soft kill) којим је тенк K2 стандардно опремљен. Претпоставља се да KAPS користи своје радаре ради упозоравања и праћења циља са електрооптичким сензорима који омогућују прецизно навођење.

Развој система KAPS започео је 2006, а завршен је 2012. године. Прве испоруке тенкова K2 почеле су 2014. године, али систем још није инсталиран ни на један испоручени тенк.

Кина је, такође, развијала свој систем активне одбране за свој тенк Type 98/99. Ради се о типу пресретачког система, иако је познато врло мало детаља. Није јасно ни да ли је овај систем инсталиран на тенк Type 99, али је у међувремену Кина одлучила да ће приоритет имати њихов тенк Type 96B на којем није инсталиран такав систем.

Јужна Африка

Један од најмодернијих система активне одбране представља Land Electronic Defence System (LEDS) који развија јужноафричка компанија *Avitronics* која је сада део компаније *Saab*. У ствари, LEDS представља целу породицу система који су типа soft kill (LEDS 50 LEDS 100) и типа hard kill (LEDS 150, LEDS 200 и LEDS 300). Систем активне одбране hard kill састоји се од два усмерена лансера велике брзине који лансирају пресретаче, а увезани су са радаром.

Основна муниција састоји се од пресретача *Mongoose 1*, шест комада по лансеру са дометом од 5 до 20 м. Пресретач има „паметни" упаљач и наводно је ефикасан у употреби против невођених и вођених противтенковских ракета, а циљеве онеспособљава фрагментационим ефектом. Компанија *Denel* развила је много већи пресретач под називом *Mongoose 3* који има домет до 300 м. За разлику од претходника, *Mongoose 3* има мали активни радарски трагач и може маневрисати. За овај већи и много свестранији пројектил наводи се да може поразити велики број разних противтенковских пројектила, укључујући кинетичке пројектиле, ракете и бомбе ваздух-земља.

Систем *LEDS/Mongoose* испробан је на многим возилима, али је за сада, према расположивим подацима, продат само систем soft kill (LEDS 50). Тренутно је компанија веома активна на индијском тржишту у покушају продаје својих система.

Тржиште система активне одбране је у нарастању, али и веома затворено, па је тешко доћи до правих података о њиховим техничким могућностима. Развој су започеле Русија и Израел, а све је више држава које озбиљно размишљају о набавци система активне одбране типа soft kill или hard kill с обзиром на врло распрострањену претњу оклопним возилима.

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ПОЗИВ И УПУТСТВО АУТОРИМА
ПРИГЛАШЕНИЕ И ИНСТРУКЦИИ ДЛЯ АВТОРОВ РАБОТ
CALL FOR PAPERS AND INSTRUCTIONS FOR AUTHORS

ПОЗИВ И УПУТСТВО АУТОРИМА О НАЧИНУ ПРИПРЕМЕ ЧЛАНКА

Упутство ауторима о начину припреме чланка за објављивање у *Војнотехничком гласнику* урађено је на основу Акта о уређивању научних часописа, Министарства за науку и технолошки развој Републике Србије, евиденциони број 110-00-17/2009-01, од 09. 07. 2009. године. Примена овог Акта првенствено служи унапређењу квалитета домаћих часописа и њиховог потпунијег укључивања у међународни систем размене научних информација. Засновано је на међународним стандардима ISO 4, ISO 8, ISO 18, ISO 215, ISO 214, ISO 18, ISO 690, ISO 690-2, ISO 999 и ISO 5122, односно одговарајућим домаћим стандардима.

Војнотехнички гласник / Vojnotehnički glasnik / Military Technical Courier (втг.мо.упр.срб, www.vtg.mod.gov.rs, ISSN 0042-8469 – штампано издање, e-ISSN 2217-4753 – online, UDC 623+355/359) јесте мултидисциплинарни научни часопис Министарства одбране Републике Србије, који објављује научне и стручне чланке, као и техничке информације о савременим системима наоружања и савременим војним технологијама. Часопис прати јединствену интервидовску техничку подршку Војске на принципу логистичке системске подршке, области основних, примењених и развојних истраживања, као и производњу и употребу средстава наоружања и војне опреме, те остала теоријска и практична достигнућа која доприносе усавршавању свих припадника српске, регионалне и међународне академске заједнице, а посебно припадника Министарства одбране и Војске Србије.

Министарство просвете, науке и технолошког развоја Републике Србије, сагласно одлуци из члана 27. став 1. тачка 4), а по прибављеном мишљењу из члана 25. став 1. тачка 5) Закона о научноистраживачкој делатности („Службени гласник РС”, бр. 110/05, 50/06-испр. и 18/10), утврдило је категоризацију Војнотехничког гласника, за 2014. годину:

за област технолошки развој:

– на листи часописа за материјале и хемијске технологије:

категорија водећи научни часопис националног значаја **(М51)**,

– на листи часописа за електронику, телекомуникације и информационе технологије:

категорија научни часопис националног значаја **(М52)**,

– на листи часописа за машинство:

категорија научни часопис националног значаја **(М52)**,

за област основна истраживања:

– на листи часописа за математику, рачунарске науке и механику:

категорија научни часопис националног значаја **(М52)**.

Усвојене листе домаћих часописа за 2013. годину могу се видети на сајту Војнотехничког гласника, страница Категоризација часописа.

Детаљније информације могу се пронаћи и на сајту Министарства просвете, науке и технолошког развоја Републике Србије.

Подаци о категоризацији могу се пратити и на сајту КОБСОН-а (Конзорцијум библиотека Србије за обједињену набавку).

Категоризација часописа извршена је према Правилнику о поступку и начину вредновања и квантитативном исказивању научноистраживачких резултата истраживача, који је прописао Национални савет за научни и технолошки развој (Службени гласник РС, број 38/2008).

У складу са овим правилником и табелом о врсти и квантификацији индивидуалних научноистраживачких резултата (у саставу Правилника), објављени рад у Војнотехничком гласнику вреднује се са 2 бода (категорија М51) и 1,5 бод (категорија М52).

Часопис се прати у контексту Српског цитатног индекса – СЦиндекс (база података домаћих научних часописа) и Руског индекса научног цитирања (РИНЦ). Подвргнут је сталном вредновању (мониторингу) у зависности од утицајности (импакта) у самим базама и, посредно, у међународним (Thompson Reuters) цитатним индексима. Детаљи о индексирању могу се видети на сајту Војнотехничког гласника, страница Индексирање часописа.

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Радови се предају путем онлајн система за електронско уређивање ASEESTANT, који је развио Центар за евалуацију у образовању и науци (ЦЕОН).

Приступ и регистрација за сервис врше се на сајту www.vtg.mod.gov.rs, преко странице ASEESTANT или СЦИНДЕКС, односно директно на линку

aseestant.ceon.rs/index.php/vtg.

Детаљно упутство о регистрацији и пријави за сервис налази се на сајту www.vtg.mod.gov.rs, страница Упутство за е-Ур: Електронско уређивање – ASEESTANT.

Потребно је да се сви аутори који подносе рукопис за објављивање у Војнотехничком гласнику региструју у регистар ORCID (Open Researcher and Contributor ID), према упутству на страници сајта Регистрација за добијање ORCID идентификационе шифре.

Војнотехнички гласник објављује чланке на српском, енглеском, руском, немачком или француском језику (arial, српска ћирилица или српска латиница, величина слова 11 pt, проред Single).

Поступак припреме, писања и уређивања чланка треба да буде у сагласности са **Изјавом о етичком поступању** (http://www.vtg.mod.gov.rs/izjava-o-etickom-postupanju.html).

Чланак треба да садржи сажетак са кључним речима, увод, разраду, закључак, литературу и резиме са кључним речима на енглеском језику (без нумерације наслова и поднаслова). Обим чланка треба да буде око једног ауторског табака (16 страница формата А4 са проредом Single), а највише 24 странице.

Чланак треба да буде написан на обрасцу за писање чланка, који се у електронској форми може преузети са сајта на страници Образац за писање чланка.

Наслов

Наслов треба да одражава тему чланка. У интересу је часописа и аутора да се користе речи прикладне за индексирање и претраживање. Ако таквих речи нема у наслову, пожељно је да се придода и поднаслов. Наслов треба да буде преведен и на енглески језик.

Ови наслови исписују се испред сажетка на одговарајућем језику.

Текући наслов

Текући наслов се исписује са стране сваке странице чланка ради лакше идентификације, посебно копија чланака у електронском облику. Садржи презиме и иницијал имена аутора (ако аутора има више, преостали се означавају са „et al.“ или „и др.“), наслове рада и часописа и колацију (година, волумен, свеска, почетна и завршна страница). Наслови часописа и чланка могу се дати у скраћеном облику.

Име аутора

Наводи се пуно име и презиме (свих) аутора. Веома је пожељно да се наведу и средња слова аутора. Имена и презимена домаћих аутора увек се исписују у оригиналном облику (са српским дијакритичким знаковима), независно од језика на којем је написан рад.

Назив установе аутора (афилијација)

Наводи се пун (званични) назив и седиште установе у којој је аутор запослен, а евентуално и назив установе у којој је аутор обавио истраживање. У сложеним организацијама наводи се укупна хијерархија (нпр. Универзитет одбране у Београду, Војна академија, Катедра природно-математичких наука). Бар једна организација у хијерархији мора бити правно лице. Ако аутора има више, а неки потичу из исте установе, мора се, посебним ознакама или на други начин, назначити из које од наведених установа потиче сваки од наведених аутора. Афилијација се исписује непосредно након имена аутора. Функција и звање аутора се не наводе.

Контакт подаци

Адреса или е-адреса свих аутора даје се на првој страници чланка.

Категорија (тип) чланка

Категоризација чланака обавеза је уредништва и од посебне је важности. Категорију чланка могу предлагати рецензенти и чланови уредништва, односно уредници рубрика, али одговорност за категоризацију сноси искључиво главни уредник.

Чланци у часописима се разврставају у следеће категорије:

Научни чланци:

1. оригиналан научни рад (рад у којем се износе претходно необјављивани резултати сопствених истраживања научним методом);

2. прегледни рад (рад који садржи оригиналан, детаљан и критички приказ истраживачког проблема или подручја у којем је аутор остварио одређени допринос, видљив на основу аутоцитата);

3. кратко или претходно саопштење (оригинални научни рад пуног формата, али мањег обима или прелиминарног карактера);

4. научна критика, односно полемика (расправа на одређену научну тему, заснована искључиво на научној аргументацији) и осврти.

Изузетно, у неким областима, научни рад у часопису може имати облик монографске студије, као и критичког издања научне грађе (историјско-архивске, лексикографске, библиографске, прегледа података и сл.) – дотад непознате или недовољно приступачне за научна истраживања.

Радови класификовани као научни морају имати бар две позитивне рецензије.

Ако се у часопису објављују и прилози ваннаучног карактера, научни чланци треба да буду груписани и јасно издвојени у првом делу свеске.

Стручни чланци:

1. стручни рад (прилог у којем се нуде искуства корисна за унапређење професионалне праксе, али која нису нужно заснована на научном методу);

2. информативни прилог (уводник, коментар и сл.);

3. приказ (књиге, рачунарског програма, случаја, научног догађаја, и сл.).

Језик рада

Језик рада може бити српски, енглески или други језик који се користи у међународној комуникацији у одређеној научној области (руски, немачки или француски).

Текст мора бити језички и стилски дотеран, систематизован, без скраћеница (осим стандардних). Све физичке величине морају бити изражене у Међународном систему мерних јединица – SI. Редослед образаца (формула) означава се редним бројевима, са десне стране у округлим заградама.

Сажетак (апстракт) и резиме

Сажетак (апстракт) јесте кратак информативан приказ садржаја чланка који читаоцу омогућава да брзо и тачно оцени његову релевантност. У интересу је уредништава и аутора да сажетак садржи термине који се често користе за индексирање и претрагу чланака. Саставни делови сажетка су циљ истраживања, методи, резултати и закључак. Сажетак треба да има од 100 до 250 речи и треба да се налази између заглавља (наслов, имена аутора и др.) и кључних речи, након којих следи текст чланка. Ако је рад написан на српском (руском, немачком или француском) језику пожељно је да се, поред сажетка на српском (руском, немачком или француском), даје и сажетак у проширеном облику на енглеском језику – као тзв. резиме (summary). Овакав резиме треба да буде на крају чланка, након одељка Литература. Важно је да резиме буде у структурираном облику, а његова дужина може бити до 1/10 дужине чланка (опширнији је од сажетка са почетка чланка). Почетак овог резимеа може бити преведени сажетак (са почетка чланка), а затим треба да следе преведени главни наслови, поднаслови и основе закључка чланка (литература се не преводи). Потребно је да се у структурираном резимеу преведе и део текста испод наслова и поднаслова, водећи рачуна да он буде пропорционалан њиховој величини, а да одражава суштину. Након резимеа на енглеском језику (проширеног сажетка) додаје се његов превод на српском, да би редакција извршила проверу и лектуру.

Кључне речи

Кључне речи су термини или фразе које адекватно представљају садржај чланка за потребе индексирања и претраживања. Треба их додељивати ослањајући се на неки међународни извор (попис, речник или тезаурус) који је најшире прихваћен или унутар дате научне области. За нпр. науку уопште, то је листа кључних речи Web of Science. Број кључних речи не може бити већи од 10, а у интересу је уредништва и аутора да учесталост њихове употребе буде што већа. Кључне речи дају се на језику на којем је написан чланак (сажетак) и на енглеском језику. У чланку се пишу непосредно након сажетка, односно након резимеа.

Систем ASEESTANT у ту сврху користи специјалну алатку KWASS: аутоматско екстраховање кључних речи из дисциплинарних тезауруса/речника по избору и рутине за њихов одабир, тј. прихватање односно одбацивање од стране аутора и/или уредника.

Датум прихватања чланка

Датум када је уредништво примило чланак, датум када је уредништво коначно прихватило чланак за објављивање, као и датуми када су у међувремену достављене евентуалне исправке рукописа наводе се хронолошким редоследом, на сталном месту, по правилу на крају чланка.

Захвалница

Назив и број пројекта, односно назив програма у оквиру којег је чланак настао, као и назив институције која је финансирала пројекат или програм, наводи се у посебној напомени на сталном месту, по правилу при дну прве стране чланка.

Претходне верзије рада

Ако је чланак у претходној верзији био изложен на скупу у виду усменог саопштења (под истим или сличним насловом), податак о томе треба да буде наведен у посебној напомени, по правилу при дну прве стране чланка. Рад који је већ објављен у неком часопису не може се објавити у Војнотехничком гласнику (прештампати), ни под сличним насловом и измењеном облику.

Табеларни и графички прикази

Пожељно је да наслови свих приказа, а по могућству и текстуални садржај, буду дати двојезично, на језику рада и на енглеском језику.

Табеле се пишу на исти начин као и текст, а означавају се редним бројевима са горње стране. Фотографије и цртежи треба да буду јасни, прегледни и погодни за репродукцију. Цртеже треба радити у програму word или corel. Фотографије и цртеже треба поставити на жељено место у тексту.

За слике и графиконе не сме се користити снимак са екрана рачунара програма за прикупљање података. У самом тексту чланка препоручује се употреба слика и графикона непосредно из програма за анализу података (као што су Excel, Matlab, Origin, SigmaPlot и други).

Навођење (цитирање) у тексту

Начин позивања на изворе у оквиру чланка мора бити једнообразан.

Војнотехнички гласник за референцирање (цитирање и навођење литературе) примењује Харвардски систем референци, односно Харвардски приручник за стил (Harvard Referencing System, Harvard Style Manual). У самом тексту, у обичним заградама, на месту на којем се врши позивање, односно цитирање литературе набројане на крају чланка, обавезно у обичној загради написати презиме цитираног аутора, годину издања публикације из које цитирате и, евентуално, број страница. Нпр. (Petrović, 2012, pp.10–12).

Детаљно упутство о начину цитирања, са примерима, дато је на страници сајта Упутство за Харвардски приручник за стил. Потребно је да се позивање на литературу у тексту уради у складу са поменутим упутством.

Систем ASEESTANT у сврху контроле навођења (цитирања) у тексту користи специјалну алатку CiteMatcher: откривање изостављених цитата у тексту рада и у попису референци.

Напомене (фусноте)

Напомене се дају при дну стране на којој се налази текст на који се односе. Могу садржати мање важне детаље, допунска објашњења, назнаке о коришћеним

изворима (на пример, научној грађи, приручницима), али не могу бити замена за цитирану литературу.

Листа референци (литература)

Цитирана литература обухвата, по правилу, библиографске изворе (чланке, монографије и сл.) и даје се искључиво у засебном одељку чланка, у виду листе референци. Референце се не преводе на језик рада и набрајају се у посебном одељку на крају чланка.

Војнотехнички гласник, као начин исписа литературе, примењује Харвардски систем референци, односно Харвардски приручник за стил (Harvard Referencing System, Harvard Style Manual).

Литература се обавезно пише на латиничном писму и набраја по абецедном редоследу, наводећи најпре презимена аутора, без нумерације.

Детаљно упутство о начину пописа референци, са примерима, дато је на страници сајта Упутство за Харвардски приручник за стил. Потребно је да се попис литературе на крају чланка уради у складу са поменутим упутством.

Нестандардно, непотпуно или недоследно навођење литературе у системима вредновања часописа сматра се довољним разлогом за оспоравање научног статуса часописа.

Систем ASEESTANT у сврху контроле правилног исписа листе референци користи специјалну алатку RefFormatter: контрола обликовања референци у складу са Харвардским приручником за стил.

Пропратно писмо (само за ауторе из Републике Србије и по посебном захтеву уредника)

Поред чланка доставља се пропратно писмо у којем треба истаћи о којој врсти чланка се ради, који су графички прилози (фотографије и цртежи) оригинални, а који позајмљени.

У пропратном писму наводе се и подаци аутора: име, средње слово, презиме, чин, звање, е-маил, адреса послодавца (ВП), кућна адреса, телефон на радном месту и кућни (мобилни) телефон, рачун и назив банке, СО места становања, број личне карте и ЈМБ грађана.

Сви радови подлежу стручној рецензији.

Списак рецензената Војнотехничког гласника може се видети на страници сајта Списак рецензената. Процес рецензирања објашњен је на страници сајта Рецензентски поступак.

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ПРИГЛАШЕНИЕ И ИНСТРУКЦИЯ ДЛЯ АВТОРОВ О ПОРЯДКЕ ПОДГОТОВКИ СТАТЬИ

Инструкция для авторов о порядке подготовки статьи к опубликованию в журнале «Военно-технический вестник» разработана в соответствии с Актом о редактировании научных журналов Министерства науки и технологического развития Республики Сербия, № 110-00-17/2009-01 от 09.07.2009 г. Применением этого Акта, в первую очередь, обеспечивается совершенствование качества отечественных журналов и их более полного включения в международную систему обмена научной информацией. Инструкция соответствует международным стандартам ISO 4, ISO 8, ISO 18, ISO 215, ISO 214, ISO 18, ISO 690, ISO 690-2, ISO 999, ISO 5122 и соответствующим отечественным стандартам.

Военно-технический вестник (**Vojnotehnički glasnik / Military Technical Courier**), втг.мо.упр.срб, www.vtg.mod.gov.rs/index-ru.html, ISSN 0042-8469 – печатное - издание, e-ISSN 2217-4753 – online, UDK 623+355/359, является мультидисциплинарным научным журналом Министерства обороны Республики Сербия, который публикует научные и профессиональные статьи, а также техническую информацию о современных системах вооружения и современных военных технологиях. Журнал следит за единой межвойсковой технической поддержкой вооруженных сил, основанной на принципах системной логистики, за прикладными и инновационными научными исследованиями, в том числе, в области производства военного оборудования и средств вооружения, и за прочими теоретическими и практическими достижениями, которые способствуют профессиональному совершенствованию представителей сербского, регионального и международного академического сообщества, и особенно служащих Министерства Обороны и Вооруженных сил Республики Сербия.

Министерство образования, науки и технологического развития Республики Сербия, согласно решению по ст. 27 абзац 1, пункт 4 и по полученному толкованию ст. 25 абзац 1 пункт 5 Закона о научно-исследовательской деятельности („Службени гласник РС", № 110/05, утверждило категоризацию Военно-технического вестника за 2014 год:

Категории в области технологического развития:

– Область материалов и химической технологии:

ведущий научный журнал национального значения **(M51)**,

– **Область электроники, телекоммуникаций и информационных технологий:** научный журнал национального значения **(M52),**

– Область механики:

научный журнал национального значения **(M52)**.

Категории в области основных исследований:

– Область математика, компьютерные науки, технические науки:

научный журнал национального значения **(M52)**.

Информацию относительно категоризации за 2013 год можно посмотреть на странице сайта Военно-технического вестника Категоризация вестника.

Более подробную информацию можно прочитать на сайте Министерства образования, науки и технологического развития Республики Сербия.

Информацию о категоризации можно посмотреть и на сайте КОБСОН-а (Консорциум библиотек Республики Сербия по вопросам объединения закупок).

Категоризация вестника проведена согласно Положению о порядке и способе категоризации научно-исследовательских результатов, утвержденному Национальным комитетом по науке и технологиям (Службени гласник РС, № 38/2008).

В соответствии с вышеуказанным Положением и табличкой с показателями классификации и категоризации индивидуальных научно-исследовательских результатов (являющейся неотъемлемой частью Положения), работа, опубликованная в Военно-техническом вестнике, оценивается следующим способом: 2 балла (категория М51) и 1,5 баллов (категория М52).

Журнал соответствует стандартам Сербского цитатного индекса – SCindeks (база данных отечественных научных журналов), а также Российского индекса научного цитирования (РИНЦ). Журнал постоянно оценивается (мониторинг) в зависимости от численного показателя важности научного журнала в самих базах, в т.ч. опосредованно в международных цитатных индексах (Thompson Reuters).

С информацией об индексировании можно ознакомиться на странице сайта журнала «Индексирование вестника».

«Военно-технический вестник» обеспечивает читателям возможность открытого доступа, в соответствии с положениями об авторских правах, утвержденными Creative Commons (CC BY). С инструкцией об авторских правах можно ознакомиться на странице **Авторские права и политика самоархивирования**, перейдя по ссылке http://www.vtg.mod.gov.rs/index-ru.html.

Работы представляются путем online системой e-Ур: Электронное издательство ASEESTANT, запущенное Центром поддерживающим развитие образования и науки (ЦЕОН).

Права доступа и регистрация в системе оформляются по адресу http://www.vtg.mod.gov.rs/index-ru.html, через страницу «ASEESTANT» или «СЦИНДЕКС» (aseestant.ceon.rs/index.php/vtg).

С инструкцией по регистрации и праву доступа можно ознакомиться по адресу http://www.vtg.mod.gov.rs/index-ru.html, на странице «Инструкция по e-Ур: Электронное издательство ASEESTANT».

Все авторы, предоставляющие свои рукописи на публикацию в редакцию журнала «Военно-технический вестник» должны пройти регистрацию в реестре ORCID (Open Researcher and Contributor ID), в соответствии с инструкцией на странице сайта Регистрация в реестре ORCID для присвоения идентификационного кода.

Военно-технический вестник выпускает статьи на сербском, русском, английском, немецком или французском языках (Arial, шрифт 11 pt, пробел Single).

Процесс подготовки, написания и редактирования статьи должен осуществляться в соответствии с принципами **Этического кодекса** (http://www.vtg.mod.gov.rs/etichyeskiy-kodyeks.html).

Статья должна содержать сюжет с ключевыми словами, введение, разработку, выводы, список использованной литературы и резюме с ключевыми словами на английском языке (без нумерации заголовков и подзаголовков). Объем статьи не должен превышать один авторский лист (16 страниц формата А4 с пробелом Single).

Статья должна быть написана на образце написания статьи, который можно скачать на странице сайта «Правила и образец составления статьи».

Заголовок

Заголовок должен отражать тему статьи. Интересы журнала и автора состоят в использовании слов, удобных для индексации и поиска. Если такие слова не содержаны в заголовке, то желательно добавить и подзаголовок. Заголовок должен быть переведен на английский язык. Эти заголовки пишутся перед сюжетами на соответствующем языке.

Текущий заголовок

Текущий заголовок пишется в титуле каждой страницы статьи с целью упрощения идентификации, в первой очереди копий статьей в электронном виде. Содержит в себе фамилию и инициал имени автора (в случае если авторов несколько, остальные обозначаются с «et al.» или «и др.»), заголовки работы и журнала (год, - объем, тетрадь, начальная и заключительная страница). Заголовки журнала и статьи могут приводиться в сокращенном виде.

ФИО автора

Приводятся полная фамилия и полное имя (всех) авторов. Очень желательно, чтобы были приведены и средние буквы авторов. Фамилия и имя отечественных авторов всегда пишутся в оригинальном виде (с сербскими диакритическими знаками), независимо от языка, на котором работа написана.

Наименование учреждения автора (аффилиация)

Приводится полное (официальное) наименование и местонахождение учреждения, в котором работает автор, а также наименование учреждения, в котором автор провел исследование. В случае сложных организаций приводится общая иерархия (напр. Университет обороны в г. Белграде, Военная академия, Кафедра военных электронных систем). По крайней мере, одна из этих организаций в иерархии должна иметь статус юридического лица. В случае если авторов несколько, и - если некоторые работают в одном учреждении, нужно отдельными обозначениями или каким-нибудь другим способом указать в каком из приведенных учреждений работает каждый из приведенных авторов. Аффилиация пишется непосредственно после ФИО автора. Должность и квалификация по образованию не указываются.

Контактные данные

Почтовый адрес и/или электронный адрес авторов указываются на первой страницы статьи.

Категория (тип) статьи

Категоризация статьей является обязанностью редакции и имеет особое значение. Категорию статьи могут предлагать рецензенты и члены редакции, т.е. редакторы рубрик, но ответственность за категоризацию несет исключительно главный редактор. Статьи в журналах распределяются по следующим категориям:

Научные статьи:

1. оригинальная научная работа (работа, в которой приводятся раньше неопубликованные результаты собственных исследований научным методом);

2. наглядная работа (работа, содержащая оригинальный, детальный и критический обзор исследовательской проблемы или области, в который автор внес определенный вклад, видимый на основе автоцитат);

3. краткая или предварительная информация (оригинальная научная работа полного формата, но меньшего объема или имеющая предварительный характер);

4. научная критика, т.е. полемика (дискуссия на определенную научную тему, обоснованная исключительно на научной аргументации) и беглые обзоры.

Однако, в некоторых областях научная работа в журнале может иметь форму монографической студии, а также критического издания научного материала (историко-архивного, лексикографического, библиографического, обзора данных и т.п.) – до тех пор неизвестного или недостаточно доступного для научных исследований.

Работы, классифицированные в качестве научных, должны иметь, по меньшей мере, две положительные рецензии.

В случае если в журнале объявляются и приложения, не имеющие научный характер, научные статьи должны быть сгруппированы и четко выделены в первой части тетради.

Профессиональные статьи:

1. профессиональная работа (приложения, в которых предлагаются опыты, полезные для совершенствования профессиональной практики, но которые не должны в обязательном порядке быть обоснованы на научном методе);

2. информативное приложение (передовая статья, комментарий и т.п.);

3. рецензия (книги, компьютерной программы, случая, научного события и т.п.).

Язык работы

Работа может быть написана на сербском, английском или другом языке, используемом в международной коммуникации в определенной научной области (русский, немецкий или французский).

Текст должен быть в лингвистическом и стилистическом смысле упорядочен, систематизирован, без сокращений (за исключением стандартных). Все физические величины должны соответствовать Международной системе единиц измерения – СИ. Очередность формул обозначается порядковыми номерами, с правой стороны в круглых скобках.

Сюжет (абстракт) и резюме

Сюжет (абстракт) является кратким информативным обзором содержания статьи, обеспечивающим читателю быстро и точно оценить его релевантность. В интересах редакции и авторов, чтобы сюжет содержал термины, часто используемые для индексирования и поиска статьей. Составными частями сюжета являются цель исследования, методы и заключение. В сюжете должно быть от 100 до 250 слов, и должен находится между титулами (заголовок, ФИО авторов и др.) и ключевыми словами, за которыми следует текст статьи. Если работа написана на сербском (русском, немецком или французском) языке, желательно, чтобы кроме сюжета на сербском (русском, немецком или французском) был предоставлен и сюжет в расширенном виде на английском языке – в качестве т.н. резюме (summary). Такой резюме должен находиться в конце статьи, после раздела Литература. Важно, чтобы резюме было в структурированном виде, и его длина может составлять до 1/10 длины статьи (оно более обширно, чем сюжет из начала статьи). Началом данного резюме может быть переведенный сюжет (из начала статьи), а затем должны следовать переведенные главные заголовки, подзаголовки и основы заключения статьи (литература не переводится). В структурированном резюме нужно перевести часть текста под заголовком и заголовком, принимая во внимание, чтобы она была пропорциональна их размеру и в то же время отражала суть.

Ключевые слова

Ключевыми словами являются термины или фразы, адекватно представляющие содержание статьи, необходимое для индексирования и поиска. Их надо присуждать, опираясь при этом на какой-то международный источник (регистр, словарь, тезаурус), наиболее приемлемый внутри данной научной области. Число ключевых слов не может превышать 10, а в интересах редакции и авторов, чтобы их частота была как можно больше. Ключевые слова даются на языке, на котором н-

аписана статья (сюжет), и на английском языке. В статье они пишутся непосредственно после сюжета, т.е. после резюме.

Программа ASSESTANT предоставляет возможность использования сервиса KWASS: автоматическое фиксирование ключевых слов из источников/словарей по выбору, т.е., которые автор/редактор воспринимает или нет.

Дата получения статьи

Дата, когда редакция получила статью, дата, когда редакция окончательно приняла статью для опубликования, а также даты, когда за истекший период были предоставлены эвентуальные исправления рукописи, приводятся в хронологическом порядке, на постоянном месте, как правило, в конце статьи.

Выражение благодарности

Наименование и номер проекта, т.е. название программы, в которой статья возникла, как и наименование учреждения, которое финансировало проект или программу, приводятся в отдельном примечании на постоянном месте, как правило, внизу первой страницы статьи.

Предыдущие версии работы

В случае если статья в предыдущей версии была изложена в устном обращении (под одинаковым или похожим названием), сведение об этом должно быть указано в отдельном примечании, как правило, внизу первой страницы статьи. Работа, которая уже опубликована в некотором из журналов, не может быть опубликована в Военно-техническом вестника (перепечатана), ни под похожим названием, ни - измененном виде.

Табличное и графическое представление

Желательно, чтобы названия всех представлений (по возможности и текстуальное содержание) были представлены на двух языках (на языке работы и на английском). Таблицы пишутся таким же способом как и текст и обозначаются порядковыми номерами с верхней стороны. Фотографии и рисунки должны быть понятны, наглядны и удобные для репродукции. Рисунки надо делать в программах Word или corel. Фотографии и рисунки надо поставить на желаемое место в тексте.

Для создания изображений и графиков использование функции снимка с экрана (скриншота) не допускается. В самом тексте статьи рекомендуется применение изображений и графиков, обработанных такими программами, как: Excel, Matlab, Origin, SigmaPlot и пр.

Ссылки (цитирование) в тексте

Оформление ссылок на источники в рамках статьи должно быть однообразным.

Военно-технический вестник для оформления ссылок, цитат и списка использованной литературы пользуется гарвардской системой (Harvard Referencing System, Harvard Style Manual). В тексте в скобках приводится фамилия цитируемого автора (или фамилия первого автора, если авторов несколько), год издания и по необходимости номер страницы. Например: (Петрович, 2010., пп. 10-20). Рекомендации о способе цитирования размещены на странице сайта «Инструкция по использованию Гарвардского стиля». При оформлении ссылок, цитат и списка использованной литературы необходимо придерживаться установленных норм.

Программа ASEESTANT предоставляет при цитировании возможность использования сервиса CiteMatcher: фиксирование пропущенных цитат в работе и списке литературы.

Примечания (сноски)

Примечания указываются внизу страницы, на которой находится текст, к которым они относятся. Могут содержать менее важные детали, дополнительные объяснения, указания об использованных источниках (напр. научном материале, справочниках), но не могут быть заменой для цитированной литературы.

Лист референций (литература)

Цитированной литературой охвачены, как правило, библиографические источники (статьи, монографии и т.п.) и она представляется исключительно в отдельном разделе статьи, в виде листа референций. Референции не переводятся на язык работы.

Военно-технический вестник для оформления списка использованной литературы применяет гарвардскую систему (Harvard Style Manual). В списке литературы источники даются в алфавитном порядке авторов или редакторов. Рекомендации о способе цитирования размещены на странице сайта «Инструкция по использованию Гарвардского стиля». При оформлении списка использованной литературы необходимо придерживаться установленных норм.

Программа ASEESTANT при оформлении списка литературы предоставляет возможность использования сервиса RefFormatter: контроль оформления списка литературы в соответствии со стандартами Гарвардского стиля.

Нестандартное, неполное и непоследовательное приведение литературы в системах оценки журнала считается достаточной причиной для оспаривания научного статуса журнала.

Все работы подлежат спец. рецензированию.

Список рецензентов Военно-технического вестника можно посмотреть на странице сайта Список рецензентов. Процесс рецензирования описан на странице сайта Правила рецензирования.

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CALL FOR PAPERS AND ARTICLE FORMATTING INSTRUCTIONS

The instructions to authors about the article preparation for publication in the *Military Technical Courier* are based on the Act on scientific journal editing of the Ministry of Science and Technological Development of the Republic of Serbia, No 110-00-17/2009-01 of 9th July 2009. This Act aims at improving the quality of national journals and raising the level of their compliance with the international system of scientific information exchange. It is based on international standards ISO 4, ISO 8, ISO 18, ISO 215, ISO 214, ISO 18, ISO 690, ISO 690-2, ISO 999 and ISO 5122 and their national equivalents.

The Military Technical Courier / Vojnotehnički glasnik (www.vtg.mod.gov.rs/index-e.html, втг.мо.упр.срб, ISSN 0042-8469 – print issue, e-ISSN 2217-4753 – online, UDC 623+355/359) is a multidisciplinary scientific journal of the Ministry of Defence of the Republic of Serbia. It publishes scientific and professional papers as well as technical data on modern weapon systems and military technologies. The journal covers inter-service technical support to the Army on the principle of logistic system support; fundamental, applied and development research; production and use of weapons and military equipment as well as other theoretical and practical achievements leading to professional development of all members of Serbian, regional and international academic communities, members of the Ministry of Defence and the Army of Serbia in particular.

Pursuant to the decision given in Article 27, paragraph 1, point 4, and in accordance with the acquired opinion given in Article 25, paragraph 1, point 5 of the Act on Scientific and Research Activities (Official Gazette of the Republic of Serbia, No 110/05, 50/06-cor and 18/10), the Ministry of Education, Science and Technological Development of the Republic of Serbia classified the Military TechnIcal Courier for the year 2014

in the field technological development:
– on the list of periodicals for materials and chemical technology,
category: leading scientific periodical of national interest **(M51)**,
– on the list of periodicals for electronics, telecommunications and IT,
category: scientific periodical of national interest **(M52)**,
– on the list of periodicals for mechanical engineering,
category: scientific periodical of national interest **(M52)**,
in the field fundamental research:
– on the list of periodicals for mathematics, computer sciences and mechanics,
category: scientific periodical of national interest **(M52)**.

The approved lists of national periodicals for the year 2013 can be viewed on the website of the Military Technical Courier, page Journal categorization.

More detailed information can be found on the website of the Ministry of Education, Science and Technological Development of the Republic of Serbia.

The information on the categorization can be also found on the website of KOBSON (Consortium of Libraries of Serbia for Unified Acquisition).

The periodical is categorized in compliance with the Regulations on the procedure and method of evaluation and quantitative formulation of scientific and research results of researchers, stipulated by the National Council for Scientific and Technological Development (*Official Gazette of RS*, No 38/2008). More detailed information can be found on the website of the Ministry of Education, Science and Technological Development.

In accordance with the Regulations and the table about types and quantification of individual scientific and research results (as a part of the Regulations), a paper published

in the *Military Technical Courier* scores 2 (two) points (category M51) and 1,5 (one and a half) point (category M52).

The journal is in the Serbian Citation Index – SC index (data base of national scientific journals), in the Russian Science Citation Index (RSCI) and is constantly monitored depending on the impact within the bases themselves and indirectly in the international (e.g. Thompson Reuters) citation indexes. More detailed information can be viewed on the website of the Military Technical Courier, page Journal indexing.

Manuscripts are submitted online, through the electronic editing system ASEESTANT, developed by the Center for Evaluation in Education and Science – CEON.

The access and the registration are through the Military Technical Courier site http://www.vtg.mod.gov.rs/index-e.html, on the page ASEESTANT or the page SCINDEKS or directly through the link (aseestant.ceon.rs/index.php/vtg).

The detailed instructions about the registration for the service are on the website http://www.vtg.mod.gov.rs/index-e.html, on the page Instructions for e-Ur: Electronic Editing - ASEESTANT.

All authors submitting a manuscript for publishing in the Military Technical Courier should register for an ORCID ID following the instructions on the web page Registration for an ORCID identifier.

The Military Technical Courier publishes articles in Serbian, English, Russian, German or French, using Arial and a font size of 11pt with Single Spacing.

The procedures of article preparation, writing and editing should be in accordance with the **Publication ethics statement** (http://www.vtg.mod.gov.rs/publication-ethics-statement.html).

The article should contain the abstract with keywords, introduction, body, conclusion, references and the summary in English language (without heading and subheading enumeration). The article length should not exceed 24 pages of A4 paper format.

The article should be formatted following the instructions in the Article Form which can be downloaded from website page Article form.

Title

The title should be informative. It is in both Journal's and author's best interest to use terms suitable for indexing and word search. If there are no such terms in the title, the author is strongly advised to add a subtitle. The title should be given in English as well.

The titles precede the abstract and the summary in an appropriate language.

Letterhead title

The letterhead title is given at a top of each page for easier identification of article copies in an electronic form in particular. It contains the author's surname and first name initial (for multiple authors add "et al"), article title, journal title and collation (year, volume, issue, first and last page). The journal and article titles can be given in a shortened form.

Author's name

Full name(s) of author(s) should be used. It is advisable to give the middle initial. Names are given in their original form (with diacritic signs if in Serbian).

Author's affiliation

The full official name and seat of the author's affiliation is given, possibly with the name of the institution where the research was carried out. For organizations with complex structures, give the whole hierarchy (for example, University of Defence in Belgrade, Military Academy, Department for Military Electronic Systems). At least one organization in the hierarchy must be a legal entity. When some of multiple authors have the same affiliation, it must be clearly stated, by special signs or in other way, which department exactly they are affiliated with. The affiliation follows the author's name. The function and title are not given.

Contact details

The postal addresses or the e-mail addresses of the authors are given in the first page.

Type of articles

Classification of articles is a duty of the editorial staff and is of special importance. Referees and the members of the editorial staff, or section editors, can propose a category, but the editor-in-chief has the sole responsibility for their classification.

Journal articles are classified as follows:

Scientific articles:

1. Original scientific paper (giving the previously unpublished results of the author's own research based on scientific methods);

2. Survey paper (giving an original, detailed and critical view of a research problem or an area to which the author has made a contribution visible through his self-citation);

3. Short or preliminary communication (original scientific paper of full format but of a smaller extent or of a preliminary character);

4. Scientific critique or forum (discussion on a particular scientific topic, based exclusively on scientific argumentation) and commentaries.

Exceptionally, in particular areas, a scientific paper in the Journal can be in a form of a monograph or a critical edition of scientific data (historical, archival, lexicographic, bibliographic, data survey, etc.) which were unknown or hardly accessible for scientific research.

Papers classified as scientific must have at least two positive reviews.

If the journal contains non-scientific contributions as well, the section with scientific papers should be clearly denoted in the first part of the Journal.

Professional articles:

1. Professional paper (contribution offering experience useful for improvement of professional practice but not necessarily based on scientific methods);

2. Informative contribution (editorial, commentary, etc.);

3. Review (of a book, software, case study, scientific event, etc.)

Language

The article can be in Serbian, English or other language used in international communication in a particular scientific field (Russian, German or French).

The grammar and style of the article should be of good quality. The systematized text should be without abbreviations (except standard ones). All measurements must be in SI units. The sequence of formulae is denoted in Arabic numerals in parentheses on the right-hand side.

Abstract and summary

An abstract is a concise informative presentation of the article content for fast and accurate evaluation of its relevance. It is both in the Editorial Office's and the author's best interest for an abstract to contain terms often used for indexing and article search. The abstract describes the purpose of the study and the methods, outlines the findings and state the conclusions. A 100- to 250- word abstract should be placed between the title and the keywords with the body text to follow. Besides an abstract in Serbian (Russian, German or French), articles in Serbian (Russian, German or French) are advised to have a summary in English, at the end of the article, after the Reference list. The summary should be structured and long up to 1/10 of the article length (it is more extensive than the abstract). It can start with the translated Serbian (Russian, German or French) abstract from the beginning of the article with translated main headings, subheadings and major conclusions to follow (Reference list is not translated). The structured summary should also contain the proportional informative parts of the text below the headings and subheadings.

Keywords

Keywords are terms or phrases showing adequately the article content for indexing and search purposes. They should be allocated heaving in mind widely accepted international sources (index, dictionary or thesaurus), such as the Web of Science keyword list for science in general. The higher their usage frequency is, the better. Up to 10 keywords immediately follow the abstract and the summary, in respective languages.

For this purpose, the ASEESTANT system uses a special tool KWASS for the automatic extraction of key words from disciplinary thesauruses/dictionaries by choice and the routine for their selection, i.e. acceptance or rejection by author and/or editor.

Article acceptance date

The date of the reception of the article, the dates of submitted corrections in the manuscript (optional) and the date when the Editorial Board accepted the article for publication are all given in a chronological order at the end of the article.

Acknowledgements

The name and the number of the project or programme within which the article was realised is given in a separate note at the bottom of the first page together with the name of the institution which financially supported the project or programme.

Article preliminary version

If an article preliminary version has appeared previously at a meeting in a form of an oral presentation (under the same or similar title), this should be stated in a separate note at the bottom of the first page. An article published previously cannot be published in the *Military Technical Courier* even under a similar title or in a changed form.

Tables and illustrations

All the captions should be in the original language as well as in English, together with the texts in illustrations if possible. Tables are typed in the same style as the text and are denoted by Arabic numerals at the top. Photographs and drawings, placed appropriately in the text, should be clear, precise and suitable for reproduction. Drawings should be created in Word or Corel.

For figures and graphs, proper data plot is recommended i.e. using a data analysis program such as Excel, Matlab, Origin, SigmaPlot, etc. It

is not recommended to use a screen capture of a data acquisition program as a figure or a graph.

Citation in the text

Citation in the text must be uniform. The Military Technical Courier applies the Harvard Referencing System given in the Harvard Style Manual. When citing sources within your paper, i.e. for in-text references of the works listed at the end of the paper, place the year of publication of the work in parentheses and optionally the number of the page(s) after the author's name, e.g. (Petrovic, 2012, pp.10-12). A detailed guide on citing, with examples, can be found on Military Technical Courier website on the page Instructions for Harvard Style Manual. In-text citations should follow its guidelines.

For checking in-text citations, the ASESESTANT system uses a special tool CiteWatcher to find out quotes left out within papers and in reference lists.

Footnotes

Footnotes are given at the bottom of the page with the text they refer to. They can contain less relevant details, additional explanations or used sources (e.g. scientific material, manuals). They cannot replace the cited literature.

Reference list (Literature)

The cited literature encompasses bibliographic sources such as articles and monographs and is given in a separate section in a form of a reference list.

References are not translated to the language of the article.

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