# INTERNATIONAL SCIENTIFIC JOURNAL



# INNOVATIONS

YEAR VI ISSUE 2/2018, SOFIA
ISSN PRINT 1314-8907
ISSN WEB 2534-8469

Publishers:

SCIENTIFIC TECHNICAL UNION OF MECHANICAL ENGINEERING
"INDUSTRY 4-0"

NATIONAL SCIENTIFIC TECHNICAL SOCIETY
AUTOMATION IN DISCRETE PRODUCTIONS

INTERNATIONAL SCIENTIFIC JOURNAL

# INNOVATIONS

YEAR VI, ISSUE 2 / 2018
ISSN (PRINT) 1314-8907, ISSN (WEB) 2534-8469

## INTERNATIONAL EDITORIAL BOARD

**CHAIRMAN:**
Prof. Dimitar Damianov — Bulgaria

**VICE-CHAIRMAN:**
Prof. Kiril Angelov — Bulgaria

**MEMBERS:**

| | |
|---|---|
| Alexander Ilyushchanka, Cor. Member | Belarus |
| Prof. Alexander Skaskevich | Belarus |
| Prof. Askar Kamerbaev | Kazakhstan |
| Prof. Atanas Kochov | Macedonia |
| Prof. Auezchan Turdaliev | Kazakhstan |
| Prof. Azem Kyçyku | Kosovo |
| Assoc.Prof. Claudia Barile | Italy |
| Assoc. Prof. Dr. Despo Ktoridou | Cyprus |
| Prof. Diana Antonova | Bulgaria |
| Prof. Dimcho Chakarski | Bulgaria |
| Prof. Feruza Zakirova | Uzbekistan |
| Prof. Galina Alekseevna | Russia |
| Prof. Günay Anlas | Tukey |
| Prof. Hristo Shehtov | Bulgaria |
| Prof. Igor Kuzo | Ukraine |
| Prof. Ivan Dimitrov | Bulgaria |
| Prof. Ivan Lamin | Russia |
| Prof. Ivo Malakov | Bulgaria |
| Assoc.Prof. Jelena Jovanovic | Montenegro |
| Assoc.Prof. Jurate Cerneviciute | Lithuania |
| Prof. Kakha Demeretashwili | Georgia |
| Prof. Lubomir Dimitrov | Bulgaria |
| Prof. Marcin Golabczak | Poland |
| Prof. Predrag Dašić | Serbia |
| Prof. Silvio Macuta | Romania |
| Prof. Simeon Simeonov | Slovakia |
| Prof. Sreten Savićević | Montenegro |
| Prof. Stefan Kartunov | Bulgaria |
| Prof. Stojance Nusev | Macedonia |
| Prof. Uwe Füssel | Germany |
| Prof. Vahram Abrahamyan | Armenia |
| Prof. Vasil Kostadinov | Bulgaria |
| Prof. Vesko Panov | Bulgaria |
| Assoc.Prof.Volodymyr Zhavoronkov | Ukraine |
| Prof. Wolfgang Drechsler | Estonia |
| Prof. Zvonimir Guzović | Croatia |

## Publishers:

**SCIENTIFIC TECHNICAL UNION OF MECHANICAL ENGINEERING "INDUSTRY-4.0"**

**NATIONAL SCIENTIFIC TECHNICAL SOCIETY AUTOMATION IN DISCRETE PRODUCTIONS**

108, Rakovski Str., 1000 Sofia, Bulgaria
tel. (+359 2) 987 72 90, tel./fax (+359 2) 986 22 40,
office@stumejournals.com
www.stumejournals.com

# C O N T E N T S

## INNOVATION POLICY AND INNOVATION MANAGEMENT

**REFORMING THE NATIONAL SYSTEM OF INTELLECTUAL PROPERTY PROTECTION IN UKRAINE**
PhD (Economics), Associate Professor Lozova G., PhD (Economics), Associate Professor, Zhavoronkov V. ..... 44

**INNOVATION OF POLISCH AND GERMAN COMPANIES**
Grego-Planer D. PhD., Glabiszewski W. PhD., Liczmańska-Kopcewicz K. PhD. ..... 48

**DEVELOPMENT OF COMPETITIVE E-MOBILITY PRODUCTS: DESIGN METHODOLOGY AND MAIN CHALLENGES**
Borut Černe, mag. ing. str., Prof. dr. Joze Duhovnik ..... 52

**BUSINESS-INCUBATORS AS PART OF INNOVATIVE INFRASTRUCTURE OF SMALL BUSINESS SUPPORT**
Cherep A.V Doctor of Economics, Professor,., Cherep O.G. PhD in Economics, Associate Professor ..... 57

**OPTIMIZATION OF CUSTOMS PROCEDURES IN THE SOUTH CAUCASUS TRANSPORT CORIDOR**
Prof. Dr. T. Kochadze, Prof. Dr. R. Mamuladze, Doctoral candidate A. Gudadze ..... 61

**REVIEW AND ANALYSIS OF CURRENT AND PROJECTED NPPS IN EASTERN EUROPE**
Chief Assistant Professor PhD eng. Dolchinkov N. T. ..... 64

## INNOVATIVE SOLUTIONS

**GREEN CARBIDES - INNOVATION IN THERMAL SPRAYING COATINGS**
Assoc. Prof. M.Sc. Guzanová A. PhD., Prof. M.Sc. Brezinová J. PhD., M.Sc. Landová M. ..... 68

**DESTRUCTION OF SILICONE PROBES OF THE ATOMIC FORCE MICROSCOPE CAUSED BY THE ELECTROSTATIC BREAKDOWN DURING SCANNING OF DIELECTRIC SURFACES**
Titarenko V., Bilokin S. PhD., Ass. prof. Bondarenko M. PhD., Ass. prof. Bondarenko Yu. PhD., Prof. Antonyuk V. Dr. Eng. ..... 72

**CHEMICAL NANOTECHNOLOGY OF MOLECULAR LAYERING AND INNOVATIVE SOLUTIONS BASED ON IT**
Prof. dr. Malygin A. ..... 75

**IMPROVING THE ECOLOGICAL INDICATORS OF GAS-FIRED BOILER PLANTS AT THE USE OF COMPLEX HEAT-RECOVERY SYSTEMS**
Doctor of Technical Sciences, Professor, Corresponding Member of NAS of Ukraine, Honored Worker of Science and Technology of Ukraine Fialko N., Candidate of Technical Sciences (Ph. D.), Senior Scientific Researcher Presich G., Candidate of Technical Sciences (Ph. D.), Senior Scientific Researcher Navrodska R., Candidate of Technical Sciences (Ph. D.) Gnedash G., Candidate of Technical Sciences (Ph. D.) Shevchuk S. ..... 79

**LOW-TEMPERATURE DISTRICT HEATING WITH DECENTRALIZED GENERATION BY HEAT PUMPS AT A RAILWAY STATION: OPTIMIZING THE SYSTEM AND CALCULATING GREENHOUSE GAS EMISSIONS**
Eng. Chicherin S ..... 82

**THE ENVIRONMENTAL CONDITIONS IN THE NEIGHBOURHOOD AND ON THE SURFACE OF THE INTERNATIONAL SPACE STATION: PART TWO**
Ass. Prof. Miteva A. M., Assoc. Prof. Dr. Karaguiozova Z. K., Ciski A., Cieślak G. ..... 85

# REFORMING THE NATIONAL SYSTEM OF INTELLECTUAL PROPERTY PROTECTION IN UKRAINE

## РЕФОРМИРОВАНИЕ НАЦИОНАЛЬНОЙ СИСТЕМЫ ОХРАНЫ ПРАВ ИНТЕЛЛЕКТУАЛЬНОЙ СОБСТВЕННОСТИ В УКРАИНЕ

PhD (Economics), Associate Professor Taras Shevchenko National University of Kyiv, Lozova G., Kyiv,
PhD (Economics), Associate Professor National Aviation University, Zhavoronkov V., Kyiv, Ukraine.
zhavor@ukr.net

***Abstract:*** *In the article the essence and content of the reform of The National system of intellectual property. Investigated the current state and problems of development of the intellectual property system, identifies the main factors: economic, social and political that prevent its development, and the prospects of its development.*
***KEYWORDS:*** *INNOVATION, INTELLECTUAL PROPERTY, COMMERCIALIZATION OF INNOVATIVE PRODUCT, PROTECTION OF INTELLECTUAL PROPERTY, THE NATIONAL SYSTEM OF INTELLECTUAL PROPERTY PROTECTION*

.

### *1. Introduction*

The reform of The National system of intellectual property began in 2016 in Ukraine. The main reasons for the reform were the slowdown in the pace of the country's innovative development, the inadequate level of commercialization of innovative products, and the obligations in the field of intellectual property protection adopted by Ukraine in the process of European integration.

The problem of the integrated development of the national economy of Ukraine on the basis of comprehensive introduction of innovations in all branches of social production remains far from being resolved. According to the Ministry of Economic Development and Trade over the last 5 years in Ukraine, about 50,000 applications for the registration of intellectual property are annually filed in. In particular, 53,454 applications were submitted in 2017, of which: 4,048 applications for inventions, 9,105 applications for the registration of utility models, 2,480 applications for the registration of industrial designs, 37,817 applications for the registration of signs for goods and services [1, p. 7]. Some of the applicants are denied in gaining the protection document, in particular in 2017 only 55.5% of the applicants received this protection. However, in the future, in the case of presence of a protection document, a significant part of intellectual property rights by their owners is not used in such a sphere of social production as intangible assets. In Ukraine, the share of intellectual capital in the assets of domestic enterprises does not exceed 1%, while in the capital structure of European and American companies this share reaches 50%. So, having a powerful scientific, technical and innovative potential, Ukraine is not able to ensure the full involvement of the results of intellectual activity in the sphere of social production, which negatively affects the rate of economic growth and the general level of the nation's welfare.

We reckon that one of the main reasons why this situation appear is the lack of an effective system of protection of intellectual property rights in Ukraine, which would facilitate the commercialization and operational transfer of the results of creative intellectual activity.

To raise the welfare of the Ukrainian nation and achieve the goals of economic growth defined in the 2020 Strategy of Sustainable Development of Ukraine, it is very important for us to attract investments for innovation, stimulate the export of innovative products, increase the output of import-substituting competitive products, and develop small and medium-sized innovative businesses in the country. Therefore, the national system of intellectual property needs reform and transformation

The National system of intellectual property protection is an aggregate of economic and legal relations, the subjects of which are state, public and private organizations that, through their own methods, tools and instruments, ensure the development of intellectual, creative activity, and protection of its results.

The reform of the national intellectual property system is defined by the Strategy of Sustainable Development of Ukraine-2020 [2], the Law of Ukraine "On Judicial System and Status of Judges" [3], the Decree of the President of Ukraine "On the formation of the Supreme Court of Intellectual Property" [4], the Concept of Reforming the Public System legal protection of intellectual property in Ukraine [5], and other regulatory and legislative acts.

The main problems in the field of protection of intellectual property rights (IP) in Ukraine:

- Lack of effective tools for IPR protection;
- low IP enforcement in the Internet;
- absence of cases of bringing to responsibility of owners of sites with pirated content;
- the presence of organized markets where the sale of counterfeit products and products with pirated content takes place;
- non-transparent mechanism for collection and distribution of royalties;
- use of unlicensed software both in commercial structures and in state bodies;
- patent trolling. [4, p.2]

The reasons that led to the aggravation of the above-mentioned problems are ineffective governance and a low level of culture in the society in the field of intellectual property rights.

The main objectives of the reform are to create an optimal, high quality and efficient system of intellectual property, to ensure effective protection of intellectual property rights, to simplify the creation and commercialization of innovative products, to support and develop the national innovation system, and the European integration of Ukraine. As important goals of restructuring, the public administration of intellectual property we can mention following - increasing transparency and eliminating corruption in this area.

In our opinion, especially the protection of intellectual property rights is the tool that can overcome corruption in Ukrainian society. As in the process of innovative activity competition arises between business entities, it stimulates the progress of society and through the mechanism of bankruptcy removes inefficient companies from the market. If intellectual property rights are reliably protected in society and the state supports innovations, inefficient enterprises will no longer succeed in overcoming their competitors through bribery.

In the process of reforming the national system of intellectual property, it is important to ensure public-private partnership. The organization of effective cooperation between universities, research organizations and private business makes it possible to create an innovative environment that facilitates the transfer of technology, the commercialization of the results of intellectual activity.

## *2. Problems and perspectives of reforming the National system of intellectual property in Ukraine*

The national intellectual property system covers national legislation on intellectual property, the state system of legal protection of intellectual property, subjects and objects of intellectual property rights. In this paper, we will focus on the problems of reforming the state system of legal protection of intellectual property.

Until 2017, Ukraine had a three-level structure for the protection of intellectual property rights. The State Intellectual Property Service provided the state policy in the field of intellectual property. The sphere of management of the State Service as an executive authority included: the State Enterprise "Ukrainian Institute of Industrial Property" (DP Ukrpatent), the Ukrainian Agency for Copyright and Related Rights (UARP), the state enterprise "Intelzahist", which dealt with issues of combating violations of rights on objects of intellectual property, mainly on objects of related rights.

In the process of reforming the intellectual property system on May 19, 2017, the State Intellectual Property Service was liquidated. In 2017 the state enterprise " Intelzahist " was also liquidated. Instead of the State Intellectual Property Service, it is planned to create a new state body, the National Intellectual Property Authority (NIPA), which corresponds to the general European practice. The NIPA will implement a state organization in the field of intellectual property management and will be financed by fees from the protection of intellectual property rights. The authority will be subordinated to the Ministry of Economic Development and Trade (previously the State Intellectual Property Service was subordinated to the Ministry of Education and Science of Ukraine). Thus, Ukraine will transition to a two-tier structure of the protection of intellectual property rights. The Ministry of Economic Development and Trade will ensure the formation and implementation of state policy in the field of intellectual property, and the NIPA shall perform certain public functions for the implementation of state policy in the field of intellectual property.

The National Intellectual Property Authority is subordinated to the State Enterprise "Ukrainian Institute of Industrial Property" (State Enterprise "Ukrpatent"). This is the only institution in Ukraine for review and examination of applications of industrial property. In 2018 it is planned to conduct an external independent audit of the activities of SE Ukrpatent in order to optimize the organizational structure and costs of the enterprise. As in the economy of knowledge the human capital is the most valuable asset of any enterprise, the new personnel policy of the enterprise provides for competitive selection of the company's management, the creation of a qualified board of directors, the involvement of highly qualified experts who are responsible for conducting a qualitative and qualified examination of submitted applications for facilities industrial property is growing every year. It is interesting to compare the ratio of filed applications and registered protection documents to inventions, utility models, industrial designs and signs for goods and services for the period from 2014 to 2017 (table .1).

In order to stimulate the innovative activity of national economic entities in the framework of the reform of the intellectual property system, it is planned to improve legislation on the mechanism and procedure for crediting fees for activities related to the protection of rights to intellectual property objects, taking into account the Association Agreement between Ukraine and the EU and the provisions of international treaties to which Ukraine joined. It is envisaged to create a single window for the issue of titles of protection to the TSO, which will enhance the transparency and effectiveness of government agencies.

Table 1

Dynamics of receipt of applications for industrial property objects and registration of titles of protection

| Objects of industrial property | 2014 | 2015 | 2016 | 2017 | 2017 in% to 2016 |
|---|---|---|---|---|---|
| *All received applications* | 44 146 | 47 819 | 51 559 | 53 454 | 103,6 |
| *Total registered* | 29 677 | 26 098 | 31016 | 29 673 | 95,7 |
| Value of applications submitted to registered companies, in% | 67,2 | 54,6 | 60,2 | 55,5 | |
| *Inventions:* received applications | 4 814 | 4 499 | 4 094 | 4 048 | 98,9 |
| registered | 3 319 | 3 014 | 2 813 | 2 590 | 92,1 |
| ratio of submitted to registered in% | 68,9 | 67,0 | 68,7 | 64,0 | |
| *Useful models:* received applications | 9 384 | 8 616 | 9 558 | 9 558 | 95,2 |
| registered | 9 196 | 8 153 | 9 044 | 9 442 | 104,4 |
| ratio of submitted to registered in% | 98,0 | 94,6 | 94,6 | 98,8 | |
| *Industrial Designs:* received applications | 2 664 | 2 080 | 2 302 | 2 480 | 107,7 |
| registered | 2 464 | 2 021 | 2 269 | 2 390 | 96,8 |
| ratio of submitted to registered in% | 92,5 | 97,2 | 98,6 | 96,4 | |
| *Marks for goods and services:* received applications | 27 280 | 32 621 | 35 605 | 37 817 | 106,2 |
| registered | 14 698 | 12 388 | 13 618 | 15 248 | 111,9 |
| ratio of submitted to registered in% | 53,9 | 38,0 | 38,2 | 40,3 | |

Source: developed by author on the base [1, c.23]

According to the data of Table.1, in the process of registration of intellectual property rights, some of the applicants receive a refusal to issue a protection document (a patent or a certificate for a sign for goods and services). In this case, the decision of the state registration authority may be appealed by the applicant in the Appeals Board or the court. An important innovation in the reform process is the creation of the Appeals Board of the National Intellectual Property Authority, a professional independent professional body, to which business entities can apply in the event of disputes in the field of intellectual property.

In particular, in 2017, the Court of Appeal and the court received 103 objections, which were distributed according to the objects of industrial property as follows: signs for goods and services - 91; invention - 11; useful models - 1. [1, c.24]

An important aspect of reforming the state system of protection of intellectual property rights is the reform of the judiciary and legal proceedings in this area. The issues of deepening the specialization of courts in disputes over intellectual property in Ukrainian society have been debated for a long time. Accordingly, there were two positions on this issue: the creation of a separate court on intellectual property or the introduction of the Chambers of Judges in local and appellate

courts. In 2018, a specialized High Court on Intellectual Property Issues, established in accordance with Presidential Decree No. 299/2017 of 29 September 2017, began its activities [4]. The court will be situated in Kiev. According to the experts' point of view, the formation of a separate court on intellectual property issues will help resolve the problem of delineating the jurisdiction of courts in the handling of cases on intellectual property matters and will ensure the application of uniform judicial practice in resolving the relevant disputes.

The creation of separate specialized courts on intellectual property issues is a worldwide trend. Today, around 90 specialized courts operate around the world. In particular, in Germany it is the Federal Patent Court, in Japan - the Supreme Court for Intellectual Property. This is due to the rapid development of the intellectual property market and the entry of countries into the World Trade Organization (WTO). Although the WTO and TRIPS agreements do not explicitly provide the creation of appropriate specialized courts, that's why many countries follow this path on their own initiative.

The Higher Court of Intellectual Property in accordance with the Economic Procedural Code of Ukraine will consider such categories of cases in the first instance:

1) cases on disputes about the rights to an invention, utility model, industrial design, trademark, commercial name and other intellectual property rights, including the right of prior use;

2) cases on disputes on registration, registration of intellectual property rights, invalidation, prolongation, early termination of patents, certificates, other acts certifying or on the basis of which such rights arise, or violating such rights are associated with them legitimate interests;

3) the case of recognition of the trademark as well known;

4) cases on disputes over the rights of the author and related rights, including disputes concerning the collective management of the author's property rights and related rights;

5) cases on disputes on concluding, amending, terminating and executing an agreement on disposal of property rights of intellectual property, commercial concession;

6) cases on disputes arising from relations related to protection against unfair competition, regarding: the misuse of designations or goods of another manufacturer; copying the appearance of the product; collection, disclosure and use of trade secrets; appealing decisions of the Antimonopoly Committee of Ukraine from the issues identified by this item.

Taking into account the specifics of the intellectual property sphere, the Supreme Court on intellectual property issues will consider disputes involving both legal entities and individuals, state authorities and local self-government. In the process of reforming the state system for the protection of intellectual property rights, references are made for liability for violation of intellectual property rights by introducing appropriate changes to the Criminal Code of Ukraine and the Code of Ukraine about Administrative Offenses.

The next step in the reform is a reform in the management system of copyright and related rights due to the reorganization of the system of collective management of proprietary copyright and related rights. The main problem in Ukraine today is that the authors' rights are violated, the authors and performers do not receive a fair compensation for the results of their intellectual and creative activity, the authors are not involved in making decisions on the distribution of collected funds by the Collective Management Organization (CMO) etc. In the course of the reforms, it is planned to create a new organization for the collective management of copyright and related rights by transforming the State Organization "Ukrainian Agency for Copyright and Related Rights" into a non-governmental organization for collective management, which will collect royalties. It is planned to introduce changes and amendments to normative and legislative acts with a view to creating a transparent mechanism for collecting, distributing and paying remuneration to subjects of copyright and related rights.

The Ministry of Economic Development and Trade drafted a law on the collective management of property rights of subjects of copyright and related rights, approved by the Cabinet of Ministers of Ukraine in December 2017. The new draft law calls for authors to take decisions on the distribution of collected funds, regulate the mechanisms of "extended" collective management, including the right holder's ability to seize rights, that is, to refuse the services of the CMO, if they do not correspond to his interests. There is also a specialization of the CMO, which will collect funds in a certain area. Therefore, users will be able to clearly determine who exactly, what kind of CMO, they have to pay money for using objects of copyright and related rights. A list of such collective management organizations will be available on the website of the Ministry of Economic Development and Trade.

The new law "On Amending Certain Legislative Acts of Ukraine Regarding the Settlement of Copyright and Related Rights" is also rather controversial. On the one hand, the project contains the necessary changes to harmonize the legislative norms and provisions in the field of copyright and related rights with European norms, corresponds to the obligations that Ukraine assumed by signing the Association Agreement with the EU. On the other hand, the adoption of this law, in the opinion of some experts, may adversely affect market participants. In particular, this concerns the new legal status of the CMO and their place in relations with TV and radio organizations. In fact, if a new law is adopted, the CMO will monopolize the authority to collect royalties. According to the law, the provider or channel can independently resolve the issue of copyright and the direction to enter into contracts directly with the rightholder. The new law clearly specifies that remuneration is transferred exclusively through the CMO. Moreover, under new changes for registration of the license the broadcasting organizations should necessarily submit the contract with CMO, that, in opinion of experts, is the additional mechanism of pressure on the tele-radio organizations. [8] The question for discussing is the question of separating interactive access as a separate way of using objects of copyright and related rights. The law also proposes changes in the part of understanding the constituents of a work that can have independent protection, namely the addition of the work next to the name of the work of the character.

The law also amends the distribution of rights to official works, in particular computer programs and databases. However, it is interesting that the general inconsistency about the rights to official works, which exists between the norms of the Civil Code and the Law on Copyright and Related Rights, is not eliminated by the project.

The law suggests that the rights to all official works which are created by employees of state bodies belong to the employer. The same is assumed for works created at the request of the state. In addition, it is determined that the proprietary rights to the computer program and the database belong to the employer, unless otherwise specified in the contract. About databases, the project also introduces a new category - the right of a special kind of producer of non-original databases. Such changes are proposed with a view to implementing the provisions of the Association Agreement.

The new regulation is also proposed for the calculation of remuneration for the sale of a work of art. So, the reward to the author (the heir) is paid if the price of selling the work (without taxes) exceeds 2 minimum wages. The amount of compensation depends on the value of the sale, for example, if it does not exceed 59 minimum salaries, then the reward will be 5% of the selling price, if the price is higher, then the percent will decrease. The duty to pay the deductions is held by the seller, regardless of whether he acts on his own behalf or as an intermediary. The procedure for recalculating such remuneration is again carried out through the CMO.

The list of cases of free use of works is expanded. In particular, it is settled that without the consent of the author and without payment of a fee, free provision of works by non-profit

libraries (except computer programs and databases) is possible. At the same time, when it comes to the use of digitized works, the granting for use is allowed only in the library premises and without the possibility of electronic copies for use outside the library. It also presupposes the legal regulation of the free use of works in an accessible format for persons with disabilities.

In addition, similar to European regulation, a norm is introduced on the authorization for the transfer and temporary storage of works, if this is part of the technological process (for example, by Internet providers).

On liability, violations are added in the form of non-payment of the stipulated remuneration, and the amount of fines increases. In addition, it is proposed as a sanction to allow the court to collect not just losses, but losses in double size.

Reforming of the state system of intellectual property protection, in our opinion, should be built not only on the basis of increasing responsibility for violation of intellectual property rights, but also include a system of measures to support and develop innovation, in particular among young people. For example, every year in Ukraine the All-Ukrainian competition "The invention of the year" is held for young Ukrainian innovators and students. In 2017, 348 works were submitted for the "Invention of the Year" competition, including 122 inventions (35% of the total number) and 226 utility models (65%), and 275 entries were submitted by scientific institutions. The competent jury selected and determined the winners who were awarded. The best invention of Ukraine is the complex of inventions "ultrasonic cavitation equipment", which can be used in various industries. Also in 2017, the All-Ukrainian competition of inventive and rationalizing projects of an environmental-naturalistic direction took place for participants from 16 to 23 years old. Every year in Ukraine, the All-Ukrainian Information Technologies Championship "Ecosoft", the All-Ukrainian competition "Intel Eko Ukraine" is held, and it helps to identify and state support of talented young people among students.

## *3. Directions of improvement and development of the intellectual property system of Ukraine*

So, the problem of reforming the national system for the protection of intellectual property rights requires a comprehensive solution by:

- making appropriate changes and provisions in the national legislation with a view to harmonizing Ukrainian and European law;
- definition of a long-term state Strategy for the development of intellectual property in Ukraine for the formation and implementation of an effective state policy in the field of intellectual property;
- creation of an effective system of state protection of intellectual property rights, which should again be provided by the state body - the National Intellectual Property Authority;
- increasing transparency and bridging corruption in this area;
- stimulation of innovative activity of national economic entities by improving legislation on the mechanism and procedure for crediting fees for the acquisition of rights to intellectual property;
- advocacy of intellectual property in the society with the aim of building citizens' respect and observance of intellectual property rights;
- reforming the judicial system to protect intellectual property rights and establishing effective work of the Supreme Court of Intellectual Property;
- establishment of an effective system of collective management of copyright.

## *4. References*


1. Promislova vlasnist' u cifrah. Pokazniki dijal'nosti ministerstva ekonomichnogo rozvitku i torgivli Ukraïni ta Derzhavnogo pidpriємstva «Ukraïns'kij institut intelektual'noï vlasnosti» za 2017 rik. Available from Internet: http://www.uipv.org/i_upload/file/promvlasnist-2017.pdf
2. Ukaz Prezidenta Ukraïni vid 12.01.2015 № 5/2015 Strategija Stalogo rozvitku Ukraïni-2020. Available from Internet: http://zakon2.rada.gov.ua/laws/show/5/2015
3. Zakon Ukraïni vid 07.07.2010 № 2453-VI «Pro sudoustrij i status suddiv» Available from Internet: http://zakon5.rada.gov.ua/laws/show/2453-17
4. Ukaz Prezidenta Ukraïni vid 29.09.2017 № 299/2017 «Pro utvorennja Vishhogo sudu z pitan' intelektual'noï vlasnosti». Available from Internet: http://zakon2.rada.gov.ua/laws/show/299/2017
5. *Association Agreement between the European Union and the European Atomic Energy Community and their member states, of the one part, and Ukraine, of the other part*. Available from Internet: *zakon.rada.gov.ua/laws/show/984_011*
6. Rozporjadzhennja Kabinetu Ministriv Ukraïni vid 1.06.2016 № 402-r «Koncepcija reformuvannja derzhavnoï sistemi pravovoï ohoroni intelektual'noï vlasnosti v Ukraïni». Available from Internet: https://www.kmu.gov.ua/ua/npas/249086258
7. Законопроект «Про внесення змін до деяких законодавчих актів України щодо врегулювання питань авторського права і суміжних прав» від 01.02.2018 № 7539. Available from Internet: http://w1.c1.rada.gov.ua/pls/zweb2/webproc4_1?pf3511=63399
8. Єfimchuk O., Sitnic'ka A.reforma u sferi zahistu avtors'kogo prava i sumizhnih prav. Available from Internet: http://jurblog.com.ua/2018/02/reforma-u-sferi-zahistu-avtorskogo-prava-i-sumizhnih-prav/

# INNOVATION OF POLISCH AND GERMAN COMPANIES

Grego-Planer D. PhD., Glabiszewski W. PhD., Liczmańska-Kopcewicz K. PhD.
Faculty of Economic Sciences and Management – Nicolaus Copernicus University in Toruń , Poland

dgp@econ.umk.pl, waldemar.glabiszewski@umk.pl, k.liczmanska@econ.umk.pl

***Abstract:*** *The changing environment and constantly growing and already global competition compel companies to keep innovating. The ability to implement innovations faster than rivals makes it possible for them to achieve the best market positions. A high level of innovation, however, does not always have to be the domain of the largest business entities. This article discusses completely different companies, which, though being smaller, and also somewhat hidden, occupy key positions on global markets. The level of their innovation often exceeds that of large corporations. The research, a fragment of which is presented here, was conducted on the German and Polish markets. Due to the specific features of this group of companies, the selection of the sample was deliberate. The research objective of the article was to assess the innovative activity of Polish and German hidden leaders.*

**Keywords**: INNOVATION, POLISCH COMPANIES, GERMAN COMPANIES, MARKET LEADRES

## *1. Introduction*

The economic development of many European countries is dependent not only on the development of large corporations, but also on a group of smaller entities that, being often world leaders, provide a significant level of exports in their home country. Professor Simon emphasised that dependence, wondering why the German and Scandinavian markets are so strongly dominating in exports. The researcher noted that a huge percentage of exports in Germany is dependent on a certain group of medium-sized entities, which in general are not familiar to the majority of the society. Deepening his research, Simon named these companies as 'hidden leaders', defining them as companies operating in niche markets (somewhat mysterious), generating revenues below three billion euros and occupying one of the first three positions on the global market in terms of the possessed share in it [Simon, Dietl 2009, p. 35]. Simon identified such companies on the German market and investigated thoroughly the way they operate. Similar research but conducted on the Polish market was done by a research team at Nicolaus Copernicus University in Toruń. In 2011, a total of 78 of such companies was identified in Poland, however 58 of them agreed to participate in the study. Subsequent searches for new Polish hidden leaders conducted in 2015 ultimately led to the identification of 94 such companies. The research on this specific group of companies conducted on the German and Polish market allowed us to draw common conclusions on the strategy of their operation. All hidden leaders share certain common characteristics, and the most important one is certainly their mysticism. Almost nobody, apart from business partners and specialists in a given industry, knows their names. Hidden champions are characterized by setting extremely ambitious goals. Each of them from the very beginning strives to take the first position in the global market. It is this goal that becomes the foundation of their success. The founders or managers of these companies are extremely ambitious. The continuity of leadership, and the great commitment that is also passed on to employees, make these long-term goals fully-achieved. A rigorous selection of employees means that they employ simply the best and extremely efficient people who identify with the company very strongly. Hidden champions have an extremely deep value chain and a very high degree of vertical integration in production. They conduct intensified research and development activities, and they are extremely cautious when it comes to outsourcing or strategic alliances. Although hidden leaders are quite authoritarian leaders as concerns principles, they give quite a lot of freedom to their employees to make and implement decisions. This is reflected in their operations. To maintain their strengths and not to lose them during intense growth periods of the company, these entities implement decentralization. They treat it as the most effective way to preserve their values. A very important pillar in the activities of all hidden champions is certainly concentration. Hidden leaders define their markets narrowly, often operate in niches, even becoming their owners. They choose a specific course of action and use their resources to follow it, trying to reach the top. Hidden champions with their narrowly defined markets would be restricted to small sizes if it had not been for the phenomenon of globalization. It is them who use it extremely effectively. Their international operations mean that even niche markets can achieve large volumes. However, this process requires them to reveal very high persistence and resistance. Both leaders and employees overcome numerous national and cultural barriers occurring within this process, thus becoming citizens of the world. The greatest strength of hidden champions is their attitude towards the client. In that respect hidden leaders constitute an unachievable benchmark. They care about their closeness and long-term relationships with their clients in all spheres of activity. They are perfectly aware that proximity with the client can lead straightforwardly to creating a competitive advantage. This article, however, raises a particularly important issue - innovation which is being followed by all of the entities studied. It is impossible to keep leading market positions with products that are of inferior quality when compared with competitive ones. Hidden champions, of course, realize this and treat innovation as the foundation of their successes. The research objective of this article is to evaluate the innovative activity of Polish and German hidden leaders.

## *2. Innovation of companies - the theoretical approach*

The literature on the subject of innovation is extremely abundant and diverse. This is related to, for example, the fact of a diverse approach to innovation shown by researchers of many professions, or to the treatment of innovations in a broad or narrow way. According to Ch. Freeman [1994, p.7], the inclusion of innovation in the strict sense means the first use of a novel product, process, system or device, and according to E. Mansfield [1968, p. 83] also of an invention. Defining innovation narrowly most often underlines the importance of technological changes that are primarily relevant to production processes [Janasz 2003, p. 53]. In turn, innovations in a broad sense relate to every idea, thing, attitude that stands out from all existing to date, especially in the context of quality. J.A. Schumpeter [1960, p. 322] identified innovation with the introduction of new products into production or the improvement of already existing ones, with the opening of a new market, using a new way of selling or shopping, using new raw materials or semi-finished products and introducing a new production organization. According to P. F. Drucker [1992, p. 41], innovation goes beyond the technological dimension, adopting the nature of social and economic changes. J.A. Allen also takes a broad approach to innovations [1966, p. 7] and claims that 'innovation is the introduction of new products, processes or procedures for widespread use'. Also M. E. Porter [1990, p. 45] treats innovations as technological improvements and better methods, as well as ways of doing something; this may be revealed in changes in the product, process, new approaches to marketing, new forms of distribution or new management concepts. M. E.

Rogers [2003, p. 12] is also a follower of taking the broad approach to innovations and claims that an innovation is 'an idea, practice or object that is perceived as new by a person or other acquiring entity'. Innovations can therefore be understood as a more or less original novelty introduced in many important and at the same time basic areas of business activity.

Innovation is the culmination of the process of creating a new reality, consisting in introducing new things in the way of proceeding or organizing and in a product or other instrument of influencing the market [Glabiszewski 2016, pp. 34-35]. Due to the quite broad treatment of innovations, which is nowadays a mainstream if not a dominant approach - certainly universally acceptable, the subject literature offers a very diverse classification of innovations. The article draws on the classification which was included in the generally accepted international methodological standard of statistical surveys in the field of innovation and was presented in a manual issued by the OECD - the Oslo Manual. The typology of innovations contained in it differentiates the following four major types: marketing, also referred to as a market one, organizational, product, and process [Oslo Manual 2005, p. 47]. There is a synergy between all these innovations. The implementation of marketing innovations increases the organization's ability to create new products and services in the form of an individualized offer that allows comprehensive customer satisfaction and significantly contributes to the success of technological innovations [Schubert 2011, p. 211].

The focus in this article is on innovativeness of companies. It should be noted, however, that many researchers identify this concept with the concept of innovation. If one comes across a different view, then it treats innovation as a certain attribute of the company, its ability to innovate. It is the ability to create something entirely new or make significant changes, acting in a way that uses this ability [Hilami, Ramayah, Mustapha, Pawanchik 2010, p. 557]. C. B. Dobni [2010, p. 334] emphasizes that the innovativeness of an organization can be even more broadly defined and include the willingness (inclination) to be innovative and the ability to introduce new products, services, ideas, or their implementation which leads to improved business performance. In this case, it can be assumed that any innovative changes that lead to achieving higher quality and lower costs within a time period that is shorter than that of rivals will increase the competitive position of the company. Innovation is a key factor in the competitiveness of business entities, and only those companies that regularly undertake the introduction of all kinds of innovations have a chance to occupy leading positions in global markets.

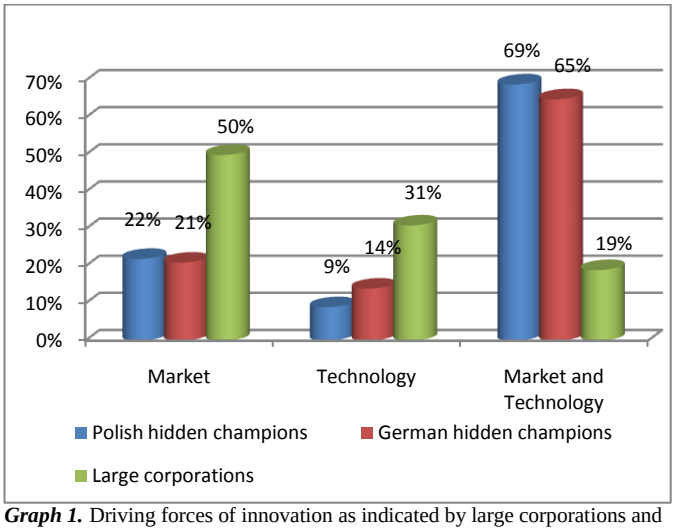
## *3. Innovation of Polish and German hidden leaders – the outcome of the research conducted*

This article is based on the results obtained from the research conducted on the German market by Professor Hermann Simon and the results of own research carried out on the Polish market. The first survey on a group of Polish leaders was conducted in 2010-2011 and apart from the sheer identification of the entities in question, an indirect survey was conducted using the telephone interview method. Another study was conducted in the years 2015-2016 using the internet survey method. A total of 71 business entities took part in the survey, which constituted 75% of the target sample.

A. Farazmand [2004, pp. 5-8] argues that innovation is a strategic instrument serving not only to build but also to expand companies' competitive abilities. Innovation is the key to progress and development in all spheres of community life, administration and technology. Innovation is a change in the pattern of the product, the method of marketing, the offered price, customer service or a change in the organization and methods of management that permeates all areas of the company's operations [Drucker 1992, pp. 42-43]. The results of the research conducted showed that this understanding is adopted by hidden champions. Their innovations do not only concern products or technologies, but also processes, systems, marketing, and services. Innovations in processes often go beyond cost reduction, leading to higher quality or greater convenience. Innovative companies identify and anticipate customers' needs actively and then respond to them appropriately, and thus create greater value for buyers [Liczmańska-Kopcewicz, Glabiszewski, Grego-Planer, Zastempowski 2018, s. 3683]. It should be emphasized that in the case of hidden champions innovation is not always associated with very radical changes. Of course, in their activities breakthrough innovations - on average at least four product and two technological innovations over a two-year time period [Grego-Planer, Glabiszewski 2016, p. 28], were often even the basis for creating completely new markets, however many hidden champions simply benefit from constant improvements. This is just the superiority of hidden leaders. Each of their products is close to achieving perfection. Hidden champions focus on doing many small things much better than competitors do, and this requires improving their products on an on-going basis.

As much as 85% of German and 75% of Polish hidden champions see themselves as technical leaders, *i.e.*, as a company that is the most innovative in terms of technology in its market. The high level of innovation can also be demonstrated by their expenditures on research and development. The increase in spending in this area is twice as high as the average in other companies. German hidden leaders spend 5.9% of their revenues on research and development activities, while Polish ones 6.05%. One in five of these companies exceeds even 9%. The innovative capacity of hidden champions can also be considered in terms of patents that are their property. The number of patent applications for 1,000 employees in large corporations is 5.8, while in the case of hidden champions it amounts to 30.6. Many hidden leaders treat their innovations protected by patents as a basic competence. It happens quite frequently that the responsibility for patents in these companies is taken over by the top management, whereas in corporations only the adequate managerial staff deal with this activity. The difference is also that the share of patents implemented is much larger in smaller companies. Therefore, hidden champions use the results of their research and development more effectively than corporations do.

Looking at the importance that technology plays in the activity of hidden champions and the volume of patents being their property, the conclusion appears to be that technology should be their greatest driving force. However, hidden leaders demonstrate an extraordinary ability to see and integrate two forces that drive their innovation. They treat both technology and the market in an equal way. These forces do not have to be mutually excluding opposites. Both market knowledge and customer needs as well as relevant technical competences are needed for effective innovation. Hidden champions are focused on both the product and the client. They perfectly use their internal specialist knowledge as well as external opportunities appearing on the market. As much as 65% of German and 69% of Polish hidden leaders indicated that they treat the market and technology as equally important driving forces. Only 21% on average say that the market is the major force. The lowest percentage of them, that is 14% of German and only 9% of Polish hidden champions indicated technology to be this driving force. The situation in large corporations looks completely different. Only 19% of these companies recognize market and technology as equivalent forces. The market was perceived as the main driving force for innovation by 50% of respondents, while 31% of these companies indicated technologies. The driving forces of innovation as indicated by German and Polish hidden champions and by large corporations are shown in graph 1.

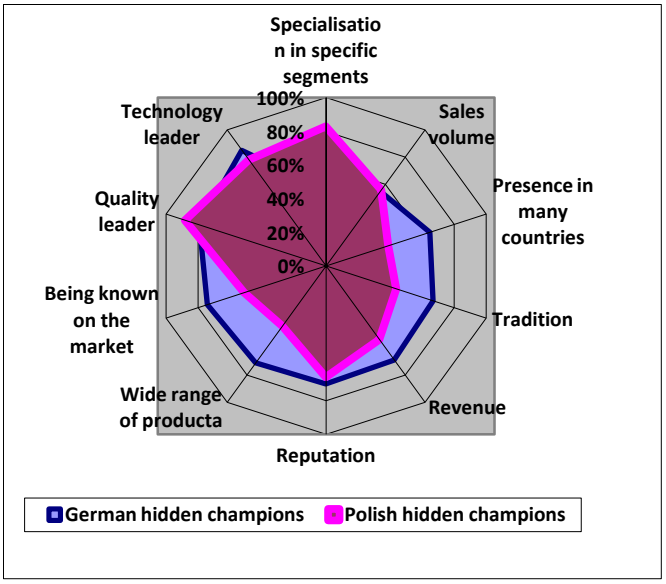



***Graph 1.*** Driving forces of innovation as indicated by large corporations and by German and Polish hidden leaders

Source: own study based on H. Simon, M. Dietl, 2009, p. 215 and D. Grego-Planer 2016, pp. 137-138.

A very important aspect in the innovative activity of hidden champions is the significant role of the top management. The top management participate in the entire innovation implementation process, not only in its initial stages. This is obviously due to the huge commitment of the management in the business and often due to their relevant extensive knowledge and practice. They frequently constitute the most active driving force of innovations. The management, however, realize the importance of people who work with them in improving products or processes. It is just adequate and highly involved staff that is the key to success. The innovative activity of respondents most often concerned the launch of new products on the market, upgrading of previously manufactured products, modernization of previously used technologies, entering new markets geographically, entering new market segments, internationalizing operations, or changing the organizational structure. Innovations included almost all aspects of their operations, beginning from the sphere of production and ending on the finance sphere.

Certainly, concentration and globalization constitute the two basic pillars of hidden champions' activities. However, it is effective innovation that allows them to strengthen their competitive position. Despite their limited resources, hidden leaders are extremely effective innovators, which allows them to occupy key positions on global markets.




***Graph 2.*** *German and Polish hidden champions - determinants of perceiving their companies as world leaders*

As shown by the research conducted, both German and Polish hidden champions consider themselves to be the leaders of quality or technology.The degree of their innovation is almost identical. Graphs 2, however, still shows the differences between Polish and German hidden champions. Certainly, Polish hidden leaders have great potential, but still in some aspects they have to catch up with their German counterparts.

## *4. Summary*

German and Polish hidden leaders are certainly impressive companies. Concentration, consistent internationalization of activities, and at the same time the use of strengths such as customer proximity, employee loyalty or continuity of leadership, which are natural features of smaller and especially family businesses are just a few important and similar aspects in their operations. However, this extremely high level of innovation is the key to their success.

Companies today have to deal with increasingly faster changes taking place in the environment [Cyfert, Bełz, Wawrzynek 2014, pp. 15-26]. One of the key features of the organization is its ability to respond flexibly to emerging changes, as well as the ability to use the acquired knowledge effectively in a shorter period of time than rivals do [Liczmańska-Kopcewicz 2017, p. 4]. It is innovation that, in addition to flexibility and risk-taking skills, is considered to be an extremely important attribute affecting the implementation of this knowledge [Han, Park 2017, p. 144]. Hidden champions are aware of the fact that being a leader means staying ahead of the competition. The companies surveyed can be classified as extremely innovative ones. This is evidenced by such aspects as the number of innovations introduced, substantial amounts of money spent on research and development activities, or continuous tracking of market changes with a view to discovering new needs. Effective innovative activity is the foundation of success achieved by the examined group of companies.

## *References*

Allen J.A. 1966, *Scientific innovation and industrial prosperity*, Longman, London.

Cyfert Sz., Bełz G., Wawrzynek Ł., 2014, *Wpływ burzliwości otoczenia na efektywność procesów odnowy organizacyjnej*, Organizacja i Kierowanie, nr 1A (159).

Dobni C.B. 2010, *The Relationship Between an Innovation Orientation and Competitive Strategy*, „International Journal of Innovation Management", Vol. 14, No. 2.

Drucker P. F. 1992, *Innowacja I przedsiębiorczość. Praktyka i zasady*, Polskie Wydawnictwo Ekonomiczne, Warszawa.

Farazmand A., *Innovation in Strategic Human Resources Management: Building Capacity In the Age of Globalization*, "Public Organization Review", march 2004, 4, 1

Freeman Ch. 1994, *The Economics of Technical Change*, "Cambridge Journal of Economics", vol. 18.

Glabiszewski W. 2016, *Potencjał absorpcyjny przedsiębiorstw finansowych w Polsce w procesie transferu innowacyjnych technologii*, Wydawnictwo Naukowe Uniwersytetu Mikołaja Kopernika, Toruń.

Grego-Planer D., *Potencjał konkurencyjny ukrytych liderów polskiej gospodarki*, Wydawnictwo Naukowe Uniwersytetu Mikołaja Kopernika, Toruń 2016.

Grego-Planer D., Glabiszewski W. 2016, *The role of innovation In the business activity of hidden leaders of the Polish economy*, "Management" vol. 20, No. 2.

Han J., Park Ch., 2017, *Case study on adoption of new technology for innovation: Perspective of institutional and*

*corporate entrepreneurship*, „Asia Pacific Journal of Innovation and Entrepreneurship", vol. 11, no. 2, 144-158.

Hilami M. F., Ramayah T., Mustapha Y., Pawanchik S. 2010, *Product and Process Innovativeness: Evidence from Malaysian SMEs*. „European Journal of Social Science", Vol. 16, No. 4.

Janasz W. 2003, *Innowacje I ich miejsce w działalności przedsiębiorstw,* [w:] Janasz W. (red.), *Innowacje w modelach działalności przedsiębiorstw,* Uniwersytet Szczeciński, „Rozprawy i Studia", t. (DXX) 446, Szczecin.

Liczmańska-Kopcewicz K. 2017, *Intraprzedsiębiorczość jako źródło innowacyjności przedsiębiorstw w sektorze FMCG,* „Management Forum", vol. 5, no. 4.

Liczmańska-Kopcewicz K., Glabiszewski W., Grego-Planer D., Zastempowski M. 2018, *The Role of the Buyer's Knowledge in Developing Product Innovations in the FMCG Sector,* Innovation management and education excellence through Vision 2020: proceedings of the 31st International Business Information Management Association Conference (IBIMA), Milan, Italy.

Mansfield E. 1968, *Industrial Research and Technology Innovation,* W.W. Horton, New York 1968.

*Oslo Manual, Guidelines for collecting and interpreting innovation data,* Third Edition, OECD, Statistical Office of the European Communities, Paris 2005.

Porter M.E. 1990, *The competitive advantage of nations,* The Macmillan Press, London.

Rogers M.E. 2003, *Diffusion of innovations,* Free Press, New York.

Schubert T. 2011, *Marketing and Organizational Innovations in Entrepreneurial Innovations Processes and their Relations to Market Structure and Firm Characteristics, "*Review of Industrial Organization", vol. 36.

Schumpeter J. A., *Teoria rozwoju gospodarczego,* PWN, Warszawa 1960.

Simon H., Dietl M., *Tajemniczy mistrzowie XXI wieku. Strategie sukcesu nieznanych liderów na światowych rynkach*, Difin, Warszawa 2009.

# DEVELOPMENT OF COMPETITIVE E-MOBILITY PRODUCTS: DESIGN METHODOLOGY AND MAIN CHALLENGES

Borut Černe, mag. ing. str.[1,2], Prof. dr. Joze Duhovnik[1,3],
Faculty of mechanical engineering, University of Ljubljana[1]
borut.cerme@lecad.fs.uni-lj.si [2]
joze.duhovnike@lecad.fs.uni-lj.si [3]

***Abstract***
*The development of an innovative product that will be widely accepted on the market is not just a question of creating innovative ideas and providing suitable functionality but also of good timing. In the last years we have seen a substantial increase in interest into e-mobility and many producers have already recognized and ventured into this niche with high rewards. E-bikes are also an emerging product in this field, which have gained a lot of interest in the last years, and are becoming widely demanded globally. Being involved in the R&D process of a similar product, namely a central drive e-bike, in collaboration with several industrial partners we have gained deep insight into the challenges of entering a by now fairly mature market with a new, high quality and competitive product. The development methodology was first based on a thorough benchmarking process and the elaboration of a functional structure that precisely describes the technical problem. This way we could identify the main functions that such a product has to fulfil and pinpoint the areas and technologies that proved to be the most critical in achieving a robust and safe system. Following the so called golden loop approach we could implement a systematical design process, where the key functional requirements could be successfully fulfilled, enabling the formation of a fully operative technical system. We focus here especially on the mechanical part of the product, i.e. the drive system and housing as this was also found to be the most challenging part of the whole development process. Due to the very demanding requirements put forth by the customer many severe challenges emerged, which could only be solved by a structured development methodology and very coordinate iterative process between all the partners. Several cues can be outlined from the experience we gained, that can serve as a guideline for the development of competitive e-mobility products.*

**Keywords:** E-MOBILITY, E-BIKE, DESIGN METHODOLOGY, GOLDEN LOOP, VDI 2221

## 1. Introduction

The term electric mobility (or shorter e-mobility) incorporates all products, technologies, infrastructures and services that provide transportation based fully or partly on electricity as power source. The main goal of e-mobility is to provide efficient and environmentally sustainable vehicles that also meet more and more stringent regulations set by governments and lawmakers as a measure to curb climate change effects and dangerous air pollution. In the last years we have seen an exponential rise in electric vehicles present on the roads globally. If we look specifically at electric cars there were only about 700k such vehicle in use commercially in 2014 [1]. By 2016 this number already rose to over 2M [2] (these figures comprise fully electric and hybrid vehicles). As noted in [3] the global e-mobility market is expected to grow to $340 billion already by 2020, which will constitute between 10 and 15% of the overall automotive market. In the report [4] the authors present a thorough overview of the electric vehicle (EV) market in Europe for 2014. Although major challenges in a large scale adoption of EVs still persist, i.e. due to the still relatively high TCO (total cost of ownership) as compared to ICE (int. combustion engine) cars and the necessity for huge investments into the EV infrastructure, they see many opportunities for established manufacturers as well as new entrants in this business.

We focus in this work specifically on a small segment of the e-mobility market, namely pedelec (or pedal-assist) e-bikes. E-bikes in general have gained a lot of traction in the last years, with China constituting the large bulk of the current e-bike market [5]. An annual growth rate of between 1 and all the way to 6% is estimated for this market between today and 2025 with the largest part of this growth attributed to Wester European countries. The current regulations in the EU limit pedelec e-bikes to a power output of 250W and a speed of 25km/h at which the assisting electric drive has to shut down leaving the cyclist to provide the full pedalling power [6]. In the work [7] the author uses a conceptual model to analyse the data from national mobility surveys conducted in the Netherlands between 2013 and 2015. It was found that the implementation of e-bikes has a positive effect on lower car usage and that car users are more willing to switch to e-bikes as compared to regular bikes. Positive findings are presented also in [8] where a trial done in the UK showed that e-bike use reduced the user's car mileage on average by about 20%, and the users in generally shown great interest to use this type of vehicle as means of transport in the future. The data presented in [9] also present realistic possibilities of the implementation of pedelecs and other e-bikes in logistics for goods delivery in urban areas.

Our industrial partners recognized the potential of pedelec e-bikes in the future of transport both as a means of commute, as well as a product for recreational use (for

example as electrically assisted mountain bikes). A growing demand for these transport devices has given a good incentive to invest substantial resources into the development of a competitive pedelec product that would meet (end possibly exceed) the demands of the present-day user. Given that the market is by now already in a fairly developed stage it turned out to be a great challenge to develop a solution that would surpass existing competitors in terms of performance and quality. A structured approach to the design of a new product can be taken by following the VDI 2222 [10] and the more updated VDI 2221 [11] guidelines which outline an efficient product development procedure which is basically divided into four main phases: Definition of the task, Finding a rough concept, Designing of a basic (preliminary) solution and Elaboration and detailing of the actual solution [12]. Following the principles outlined in [13] the so called concurrent product development principle can be applied, which enables further timewise optimization of the R&D process.

## 2. Methodology

The industrial partners involved in the project identified the e-mobility and specifically the pedelec market segment as having big potential for growth in the future, especially in western European as well as other industrialized countries. A thorough examination of existing pedelec solutions on our targeted market served as basis for the definition of initial specifications, onto which the product development process could start.

The main focus was in our case the development of the product's mechanical system, i.e. the drive train and its housing. Further benchmarking was carried out by our R&D team, with which the key functionalities of pedelec drives were identified. The process was narrowed down to four main competitors:

- Bosch eBike systems (Performance Line®)
- Brose e-bike System®
- Shimano Steps E8000®
- Yamaha PW® and PW-X® series

A review of existing and pending patents enabled us also to identify which technical solutions for a given function we should avoid or develop in such a way that it wouldn't infringe any of the uncovered patents.

The VDI 2222 and VDI 2221 guidelines advocate a very structured product development approach, divided into several partially overlapping phases, which are in terms subdivided into multiple design stages. During the process we iterate back and forth between stages until a solution ready for physical realization is produced. Typically it is necessary to divide the designed product into modules that can be developed in parallel which enables an accelerated design process. These modules can be viewed as independent functional subsystems. It is however very important to precisely define what the inputs and outputs of each module are in terms of mass, energy and information flow. Along with recommendations given by the VDI guidelines, our product development phase followed also the so called golden loop approach presented in [14], [15] and [16]. Similarly to the VDI guideline the golden loop approach dictates an iterative design method where the latter is carried out as a sequence of loops. In the first loop a functional structure is defined, that fulfils the demands posed by the identified problem and the defined project specifications, the technical principles for each function are chosen and a preliminary model (typically using CAD software) is formed. Consultation with experts and project managers leads to identification of possible issues and necessary upgrades which in terms leads to a new design iteration loop. With each loop the specifications are rechecked, if necessary the functional structure is updated in case any new sub-functions are identified and the design model is suitably upgraded. In order to keep the development process in a manageable time frame and the number of iterations as small as possible we need to maintain effective communication channels between all the partners involved in the project. Efficient time and cost planning, involvement of industrial designers, technologists and toolmakers during the R&D process are also paramount for a successful and fast project completion. An indispensable tool for a quick identification of possible problems and failure modes has proven to be the established and widely used FMEA method, which was carried out several times during the process. With each iteration a more and more detailed design model emerges, until a solution ready for technical documentation and prototype production is achieved.

Along with the use of a suitable CAD software that is nowadays indispensable in any product design project our experience showed that also high quality analysis software is crucial. While standards and analytical tools enable a service life estimation of machine elements like bearings, shafts and gears, more custom load bearing components cannot be suitably dimensioned and optimized without modern numerical analysis tools like FEM or experimental testing.

## 3. Main challenges

The pedelec solution we aim at developing is primarily intended for integration in mountain bikes and is targeting especially Western European markets. As such it needs to fulfil first the nominal power and speed requirements dictated by the EU directives [6]. It is however also necessary that the drive provides increased power output in cases of steep climbs and off-road use for a sufficient amount of time. Furthermore we needed to provide adequate robustness of the whole system to withstand all the overloads that might occur during use. A brief summary of the main drive requirements is presented in Tab. 1. As visible the peak output power exceeds substantially the nominal power. Also the drive system and housing have to withstand high force overloads in any given direction. Furthermore specific attention must be given to elevated noise levels, housing outer surface temperatures and also suitable water tightness. The whole system also has to be enclosed in an as discrete volume as possible.

| Parameter | Symbol [unit] | Value |
|---|---|---|
| Nominal output power | $P_n$ [W] | 250 |
| Peak output power (5min continuous) | $P_p$ [W] | 770 |
| Overloads | $F_o$ [N] | 4500 |
| Cadence range | $n_c$ [min$^{-1}$] | 40 -120 |
| Max. noise level | $L_p$ [dB] | 55 |
| Max. out. surface temp. | $T_o$ [°C] | 60 |
| Water tightness | Class. | IP 56 |

Tab 1. Main drive requirements

The main function that the drive needs to fulfil is efficient power transfer and a suitable transmission ratio from the battery powered DC motor in use to the output shaft connected to the bike chainring. A two stage gear transmission was chosen with the first stage consisting of a planetary gear train and the second of a normal gear pair as shown in Figure 1. This configuration was chosen due to its simplicity compactness and relative efficiency (less components means smaller aggregate energy losses). Developing a drive train design with very limited dimensions that would withstand the required service life while still providing a smooth and quiet ride and suitable price/performance proved to be a rather demanding task. Several measures were applied (some still being in the testing phase) to achieve the wanted performance. The main challenges in the design of the gear train and possible technical solutions are noted in Tab. 2. Of special concern here was the (first) planetary gear stage, which runs on much more elevated rotational speeds than the second stage and can hence produce much higher noise levels. Several measures were necessary to achieve smooth running conditions there. First of all a helical gear geometry was used, that enables an increase contact ratio and lower transmission error which in terms positively influences the noise level. Furthermore it was necessary to switch from metals to polymers as structural materials for the planet and ring gears, while retaining a steel sun gear. These changes lead to several additional performance issues that are being solved by a combination of measures mentioned in the table below.

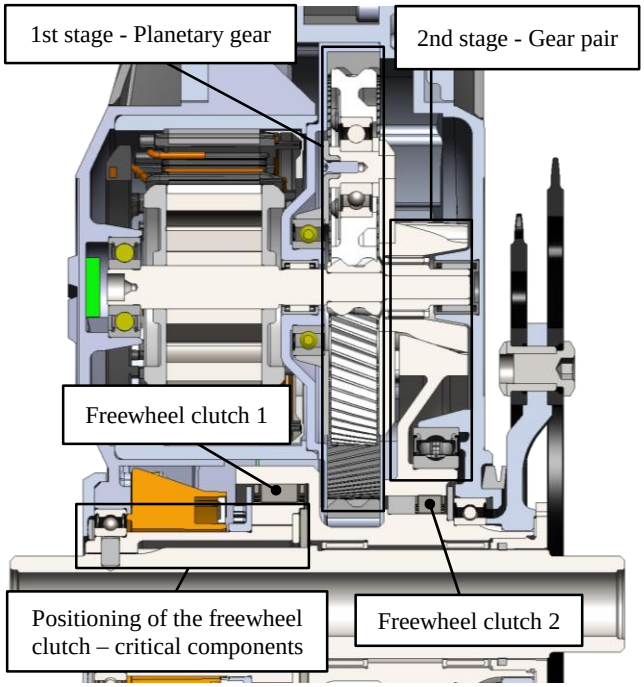



Figure 1. Pedelec drive train solution

A range of tools was necessary for the design of a suitable drive train solution. The initial geometry design and structural evaluation of the used gears was performed using software KissSoft. The latter follows available standards and established models to estimate the life expectancy of the developed drive while also enabling CAD model generation for further gear production. For metal gear design the software offers fairly reliable evaluation methods while for designing polymer gears things are somewhat less trivial. Especially for high performance plastics like PEEK used in

| *Performance goal* | *Technical solution* | *Resulting issues* | *Further upgrade* |
|---|---|---|---|
| Suitable service life | Adequate gear sizes (module, width, etc.) | Exceeded volume limitations | Geometry optimization |
| | High performance materials | Higher cost | Price/performance compromise |
| | Lubrication | Leakages | Suitable sealing |
| Smooth and quiet running | Switch metals with plastics on first gear stage (for planet gears and ring gear) | Lower accuracy of the produced gears | Switch gear injection modelling with milling (more expensive) |
| | | Lower stiffness of the gears | Use of high performance plastics (i.e. PEEK or similar)<br>Surface treatment of the sun gear's teeth<br>Use of wear reduction coatings |
| | | Lower wear resistance | Wear resistance fillers (PTFE or graphite) |
| | | Temperature sensibility | Gear geometry optimization - reduced contact stresses and sliding speed during gear meshing<br>Lower frictional coefficient – suitable material pair choice |
| | Helical gear design with suitable helix angle | High axial forces | Suitable design of associated components |
| Reduced friction without use of oil | Grease application | Poorer frictional conditions | Appropriate grease for given running cond. |

Tab 2. Gear drive train design challenges

our case for the planet gears (commercial type Victrex 650g) the available data necessary for the evaluation are very incomplete. Hence we needed to turn to experimental tests using a testing rig developed at our institute [17]. The results achievable for a simplified gear geometry can be extrapolated and projected to the running conditions present on the planetary stage to obtain a rough service life estimation. A possible and in fact typical failure mechanism present on polymer gears is the effect of wear, especially common in application where we have steel-polymer gear meshing. Wear is driven by several factors, most importantly the sliding contact conditions and resulting temperature increase due to friction which typically accelerates this process. Several evaluation tools are being developed by our team to predict the frictional thermal effects, and consequent probabilities of excessive wear. Figure 2 presents some exemplary results for the evaluation of the thermal state present during gear meshing of a POM-PA66 polymer gear pair. The overall temperature rise is a sum of two temperature components- the local flash and long term nominal temperatures. These results can help estimate whether the chose loading conditions are critical for the desired service life of the gear pair.

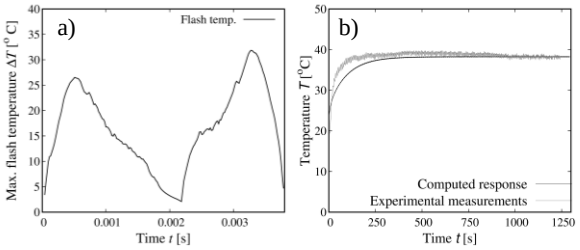



Figure 2. Evaluation of the flash (a) and nominal (b) temperature rise due to frictional effects during gear meshing (example results for POM-PA66 gear pair with 1Nm torque load and 1392rpm)

The pedelec drive also has to provide three modes of operation:

1. Simultaneous action by the drive and cyclist.
2. Independent running of the drive train.
3. Independent pedalling by the cyclist.

These modes in essence provide different types of power transfer to the frontal bike chainring. They can be achieved in a single drive mechanically by a suitable configuration of freewheel clutches as visible in Figure 1. A combination of two frictional sprag freewheel clutches was used to achieve the desired operation modes and here again several challenges emerged in achieving the desired power transfer. This type of freewheel clutch requires rather demanding preparation of the running surfaces both on the shaft and hub. A surface hardness of 700+100HV is necessary with a depth of 1.3mm and a roughness grade Ra0.4 or less. While this is achievable with different alloy steel grades, the required hardness depth can result in excessive brittleness and fracture of the associated hub or shaft. A further aspect to consider is the positioning of the clutches. Even though both the hub and shaft are produced in the required tolerances it is possible that an insufficient concentricity is achieved due to the tolerance chain of all other associated components. In our case this proved to be the case for the larger Freewheel clutch 1, with the main issue being the housing bearing seat tolerances and a spline joint used between the main shaft and the sleeve used for pedalling torque measurement (Figure 3). Initially the positioning of the sleeve was achieved by the contact of the spline teeth flanks as seen in Figure 3a which resulted in inadequate concentricity. A suitable positioning that enabled the desired functionality of the clutch was achieved by transferring the centring surfaces from the joint teeth flanks to the inner diameter of the spline.

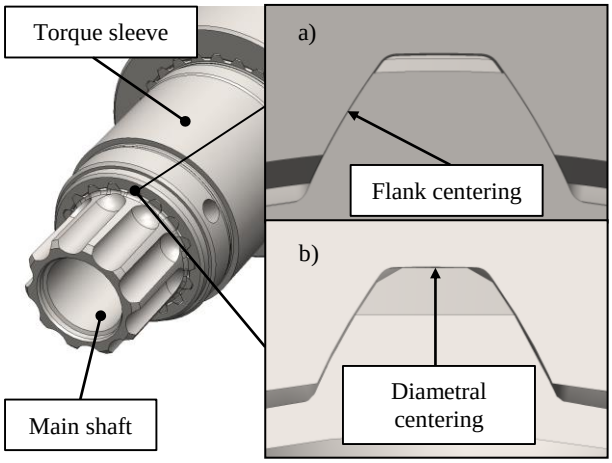



Figure 3. Torque sleeve and main shaft spline joitn: (a) flank positioning- insufficient positioning accuracy; (b) outer diameter positioning – adequate centering of the sleeve

Due to the all mentioned requirements and complications which led to rather costly upgrades we decided to switch to a simpler and more robust clutch solution where the one-way torque transfer is provided by detents and a suitably designed ratchet (Figure 4a). This custom solution was designed based on results from FEA, with which we could attest that the anticipated loads wouldn't result in too high structural stresses (Figure 4b).

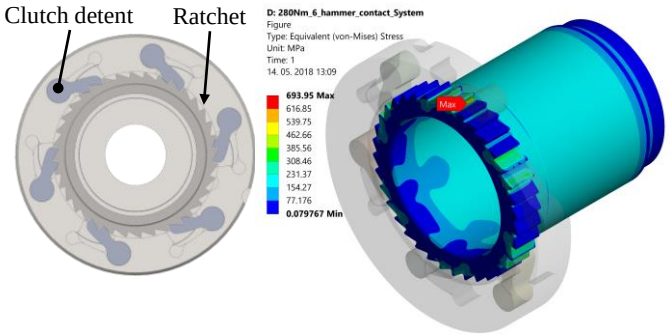



Figure 4. (a) Custom freewheel clutch solution as a cheaper and more reliable alternative to commercial sprag clutches; (b) evaluation of internal stresses due to pedalling torque transfer using FEA.

The presented problems are only a part of the challenges that were met during the design process. With them we wish to point out the fact that even with a structured design methodology it is not always possible to predict and resolve in advance all the functionality issues that might occur. Small inconsistencies like inadequate tolerance chains or inappropriate surface finishes can set back the project for weeks or even months and add to unnecessary project costs. While the use of modern design tools proves indispensable for a rapid design development, the expertise of the team members and a suitable project management with regular design checks and open communication channels between all involved parties is really crucial for a successful project completion.

## 4. Conclusion and discussion

A structured design process based on the VDI 2222 and VDI 2221 guidelines and following the golden loop approach is presented as was applied to the development of a novel pedelec central drive system. The process was split into several stages and the product divided into a manageable number of independent modules. Following this approach the developed product can be brought to a functional level if a team with suitable expertise is involved. However, even with expertise and modern design tools, the complexity of the system made it difficult to predict whether the service life and all the functionality requirements would be met. The production of several iterations of prototypes and extensive testing proved essential in identifying several remaining weaknesses that needed to be properly addressed and corrected. A systematic R&D approach can however substantially reduce the number of needed design iterations and lead to a much faster transfer of the product from the proverbial drawing board to the production line.

## 5. Bibliography


[1] Automotive world, "E-mobility and the untapped potential of emerging markets," 29 October 2015. [Online]. Available: https://www.automotiveworld.com/analysis/e-mobility-untapped-potential-emerging-markets/. [Accessed 7 May 2018].

[2] International Energy Agency, "Global EV Outlook 2017 - Two millions and counting," OECD, 2017.

[3] A.T. Kearney, "eMobility: The Long Road to a Billion-Dollar Business," Korea, 2011.

[4] McKinsey&Company, "Electric vehicles in Europe: gearing up for a new phase?," Amsterdam Roundtable Foundation, 2014.

[5] R. Citron and J. Gartner, "Exclusive summary: electric bycicles, Li-Ion and SLA E-Bikes: Drivetrain, Motor, and Battery Technology Trends, Competitive Landscape, and Global Market Forecasts," Navigant Research, 2016.

[6] *COUNCIL, DIRECTIVE 2002/24/EC OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 18 March 2002 relating to the type-approval of two or three-wheel motor vehicles and repealing Council.*

[7] M. Kroesen, "To what extent do e-bikes substitute travel by other modes? Evidence from the Netherlands," *Transportation Research Part D,* vol. 53, pp. 377-387, 2017.

[8] S. Cairns, F. Behrendt, D. Raffo, C. Beaumont and C. Kiefer, "Electrically-assisted bikes: Potential impacts on travel behaviour," *Transportation Research Part A,* vol. 103, pp. 327-342, 2017.

[9] R. Nocerino, A. Colorni, F. Lia and A. Lué, "E-bikes and E-scooters for smart logistics: environmental and economic sustainability in pro-E-bike Italian pilots," *Transportation Research Procedia,* vol. 14, pp. 2362-2371, 2016.

[10] VDI-Richtlinie 2222, "Konzipieren technischer Produkte," VDI-Verlag, Düsseldorf, 1973.

[11] VDI-Richtlinie 2221, "Methodik zum Entwickeln und Konstruieren technischer Systeme und Produkte," VDI-Verlag, Düsseldorf, 1993.

[12] M. Bader and M. Fallast, "The Development Process as a Complex and Interdisciplinary Team Based Challenge," in *New Technologies, Trends, Innovations and Research*, IntechOpen, 2012, pp. 327-346.

[13] J. Kušar, J. Duhovnik, J. Grum and M. Starbek, "How to reduce new product development time," *Robotics and Computer-Integrated Manufacturing,* vol. 20, pp. 1-15, 2004.

[14] J. Duhovnik, "Development Process with Regard to Customer Requirements," *Concurrent engineering: Research and Applications,* vol. 14, no. 1, pp. 67-82, 2006.

[15] J. Benedičič, R. Žavbi and J. Duhovnik, "An oportunity search method for new products development," in *International Design Conference - Design 2008*, Dubrovnik.

[16] Ž. Zadnik, *Matrix of functions and functionalities in preliminary product development process, doctoral work,* Ljubljana: Faculty of mechanical engineering, University of Ljubljana, 2012.

[17] D. Zorko, S. Kulovec, J. Duhovnik and J. Tavčar, "Different teeth profile shapes of polymer gears and comparison of hteir performance," *The JSME International Conference on Motion and Power Transmission, Proceedings of MPT2017-Kyoto,* February-March 2017.

# BUSINESS-INCUBATORS AS PART OF INNOVATIVE INFRASTRUCTURE OF SMALL BUSINESS SUPPORT

Cherep A.V Doctor of Economics, Professor,., Cherep O.G. PhD in Economics, Associate Professor
Zaporizhzhya National University, Ukraine

***Abstract.*** *The interrelation between innovation infrastructure of small businesses support with the creation and development of business incubators is analyzed. Imperfect system of funding and material and technical support development of business in Ukraine is established. It was determined that small and medium business accelerates economic restricting, improve organizational efficiency of national resources. So the creation of business incubators is very important for business and sustainable development in the economic situation of the country. The authors give the basic principles of state policy building for small businesses. Foreign experience in creation and development of business incubators is adapted to local conditions by combining and combining different forms, methods and means of regulation and support domestic enterprises. The authors propose the business incubator model which may promote development and management small business.*

**Introduction.** The problem of creating appropriate conditions for innovation spreading is highly relevant for the national economics. Its solution serves as a guarantee of technological transformations in production. The degree of innovative development of the national economics depends upon innovation. The process of innovation infrastructure formation, which should provide favorable conditions for the scientific research activation have particular importance.

**Literature review.** Features of innovation infrastructure creation in Ukraine's economics are highlighted in the works of many scientists. For example O.I. Amosha, I.P. Buleyeva, G.Z. Shevtsova [1], L.M. Vasilieva [4], V.M. Goncharova, Yu.N. Derechynska [7], M.V. Zhuk [8,9], O.M. Borodina [9], V.V. Zyanko [12], I.M. Kopchenko [13, 14], V.V. Lytvyna, N.O. Matviychyk-Soskain [16], G.O. Androshchuk, I.B. Zhyliaiev, B.G. Chizhevsky, M.M. Shevchenko [20] etc.

**Results.** While analyzing the innovation infrastructure components scientists' attention is devoted to the characterization of such modern organizational forms as techno parks, technopolises, innovation funds, venture funds, etc. However, there are very limited studies concerning also important component of the infrastructure – business incubators, although they play an outstanding role in the development of innovation activities.

As a whole the functioning of the economics depends on the enterprise development. However, a clear strategy of regulation has not yet been elaborated in Ukraine. The program of this form development is not substantiated, the system of financing and logistical support for the business formation and development is imperfect. Legal and organizational issues also exist. Therefore, for the expansion of entrepreneurship and sustainable development it is very important to analyze the world experience of enterprises and the possibility of its application in Ukraine.

The small and medium business is the important part of modern entrepreneurship. It accelerates structural economic reingeneering, improves organizational efficiency of national resources using. With well-balanced state policy domestic small and medium businesses can create thousands of new work places and contribute to Ukraine's becoming an economic developed state.

During the independence years of national economics small and medium enterprises gradually develop in Ukraine. Almost half of the working population of the country works in this sector. Positive dynamics of its development takes place because of the introduction of a simplified system of taxation, accounting and reporting of small businesses, a number of progressive norms of regulatory policy, the reform of the permit system, etc. In quantitative terms the development of small and medium enterprises in Ukraine has gradually become closer to the development of small business in the EU. At the same time, it should be noted that domestic business exists and develops in the difficult conditions of the transformational economics and meets a multitude of problems. The decrease in the viability of small and medium business is connected with significant tax burden, the presence of different kinds of administrative barriers, limit financial credit, weak financial, technical, financial, managerial and human resources component of small businesses [13, p. 117].

Small entrepreneurship is an important element of a market economics. The state cannot steadily develop without it. Formation of favorable conditions for small businesses provides income for population and the taxes for local budgets. However, in Ukraine, state support for small business development has not yet been included in the main directions in the administrative and territorial unit development.

Small business is supported only at the regional level. The participation of local administrations in its development is negligible. Although this level of management is closest and accessible to entrepreneurs. So there is a need to shift the emphasis of the small business state support to the local level. Also full decentralization of regional support for small business development is impossible [5, p. 52].

State support for small businesses at the regional and local levels have not been widely provided, despite the fact that the interests of the authorities of different levels coincide. This is due to the lack of funding from the budget, and the lack of interest of officials in the development of small business.

From the point of view of the entrepreneur, the state should create conditions for maximizing profits, minimizing risk, protecting property and identity of the entrepreneur, etc. From the point of view of the state entrepreneur should ensure the growth of social welfare support for employment, economic growth, political stability, etc. [15, p. 39].

The market economics is not able to automatically adjust the economic and social processes in favor of each employer and society as a whole. The task of state policy is to achieve a general equilibrium in which the state seeks to maintain a competitive balance, that is, when consumers maximize the value of the function of utility, and entrepreneurs maximize the profit.

Establishing an effective and effective mechanism for the formation and implementation of a state policy for supporting small businesses in Ukraine undoubtedly require creative borrowing world achievements in this area, first of all, the experience of countries with developed market economies.

Small businesses support around the world is considered to be the responsibility of the state, because small businesses are inferior to large enterprises for the possibilities of modernization, marketing research, financial resources, and the competitiveness of goods and services.

In an unstable economic situation a domestic small business needs a protectorate of the state. But effective support mechanism of the entrepreneurship development in Ukraine has not yet been established. Financial assistance provided by Ukrainian Support Fund, National Endowment for farms and State Innovation Fund is quite small [7, p. 86].

First of all, business needs legal support. Many laws that gave impetus to the development of entrepreneurship in the country no longer response the requirements of time and need improvement.

Financial assistance, which provides for the provision of soft loans and their guarantee, should place one of the key places.

To promote small business development is possible only by combining and combining different forms, methods and means of regulation and support, chief among which is [8, p. 35]:

- state support for the production and sale of products, which involves providing state orders, leasing equipment on preferential terms, customs privileges, facilitating the export of goods and services to international markets, reduction of rental rates;
- financial and credit support, providing for direct guaranteed loans for development and expansion of activities, development of preferential lending programs, reduction of interest rates on loans, state guarantee of obtaining loans, targeted subsidies and budget financing of the economics in accordance with the priorities of the state's economic policy;
- favorable tax policy, which provides for preferential taxation of activities and reduction of tax burden on small businesses;
- informational and advisory support for the creation and development of small business enterprises, training of specialists at the expense of state funds in specially created centers, free professional counseling of entrepreneurs.

Depending on the chosen objectives the state can: restrain the development of entrepreneurship in general and small in particular, create extremely unfavorable conditions for their development, for example, to set high taxes on enterprise activity, refuse to protect the interests of owners, etc.; to be an outside observer without interfering; the initiator of entrepreneurial development, taking measures for the search and involvement of new economic agents in the business process [13, p. 118].

The basic principle of the state policy development in the field of small business is the combination of the non-interference in the entrepreneur's production principle with the principle of social partnership. The state task is to build a social-market economics that realizes achievements for both economic and social purposes. An important principle of state policy is the principle of decentralization and empowerment of regions and local self-government in the sphere of small business. The state policy in the field of small business should be built in compliance with the principle of stability of the regulatory regime. This is a determining factor for the environment of small business. Objectively important socio-economic role of small business in the Ukrainian economics implies the need for high rates of its formation and strengthening in the system of national economics. However, the small business development in Ukraine does not response the requirements of a market economics. The unfavorable tendencies of small business development are connected with the national political, economic and social problems and peculiarities of small business as a subject of the economics. In connection with this fact, the necessity of accelerated development of small business causes its active support from the state.

Compared to generally accepted indicators in the world, the level of small business development in Ukraine is clearly insufficient. Thus, on average 1 thousand people there are 7 small enterprises in Ukraine, while in the countries of the European Union there are not less than 30. The share of employed at small enterprises is about 30%, while in EU this indicator is 65% [23, p. 27].

The largest concentration of small business is in the capital of Ukraine (8.9% of the total) and large industrial regions: Dnipro (7.3%) and Kharkiv (7%). The smallest concentration of small business is in the western regions (Chernivtsi (1, 8%), Ternopil (1.9%) region).

Today in Ukraine there are many problems of small business, for example [15, p. 42]:

1. Corruption and red tape;
2. High level of taxation, which decreases profitability of small businesses, increases the probability of bankruptcy;
3. Ineffective mechanisms for financing and insurance of small business;
4. Lack of social security and business education for the staff of small businesses;
5. Policy and economic instability and inconsistency, and complexity of the legislation.

Thus, the creation of new small businesses depends on the authorities. In our view, the next measures should create a favorable business environment [5, p. 53]:

- significant simplification of rules and procedures for new businesses;
- eliminating the contradiction in the legislative framework, ensuring its transparency and stability;
- control by public organizations for the activities of government officials;
- creating an effective feedback system to inform relevant structures about the corruption actions of government officials.

Thus, it can be concluded that state support for small businesses is an integral part of public policy, which should not only create favorable conditions for the expansion of small enterprises, but also directly support them. In this regard, the priority directions of improvement of the mechanism of state support of small business should be:

- legislative improvement for small businesses regulating;
- financial and credit support for small business development;
- introduction a system of organizational and educational measures fort raising the knowledge, skills, professional level in business;
- consulting development;
- promoting the development of leasing companies.

In the whole business incubator is an organizational structure of the scientific and technical sphere, which should provide appropriate conditions for small innovative companies. Such companies implement the original scientific and technological ideas.

In Ukraine the first business incubators appeared in the 90 years of the last century, although the idea of creating them abroad appeared in the 1950s in the USA. A bit later business incubators became widespread in Western Europe.

The original idea is very simple: it is necessary to create an organization that fully cares about the newborn-company. Such company does only the first steps on the path to innovative business. Business incubator provides a range of services, including providing small firms with rental accommodation, facilitating their registration, creating conditions for the initial capital formation, providing consulting, training etc.

In our opinion, the main purpose of business incubators can be described as providing "growth scenario" for small firms in the material, financial, educational means; creating conditions for their adaptation.

As a rule small firms are in the incubator for 3-4 years, than leave it to become functionally independent.

The experience of developed countries shows that small firms after incubator is more stable and durable compared with small enterprises that have not undergone the previous adaptation. According to data from the experience of the first business incubators in the United States, 30% of start-ups moved from small to medium business. At the same time among self-initiated firms only 12% became entrepreneurs [1].

There are different types of business incubators: non-profit; profitable; branches of higher educational establishments.

Non-profit business incubators operate at the expense of local authorities. Profitable business incubators require from firms-clients partial reimbursement of their expenses. Incubators-branches of higher education are created with the support of large enterprises, commercial banks, investment funds, which can provide the necessary financial resources. Such branches use intellectual resources, laboratory facilities and research institutes, their rooms, library etc.

In Ukraine business incubators exist in higher schools and regions. Regional incubators were created with the support of other countries. Currently, there are business incubators in the Dnipro and Kyiv Technical University. Funded by international organizations there is business incubator "Kharkiv

Technologies", Innovation Center in Kyiv, innovative business incubator in the Bila Tserkva.

Business incubators can be created as a separate organization, and as part of technical parks, technopolicies. For example, a business incubator "Kharkiv Technologies" is part of the technical park "Institute for Single Crystals".

In 1998 it was founded Ukrainian association of the business incubators and innovation centers.

In the whole there are 71 business incubators in Ukraine with total area of 8997 square meters. They have created 460 businesses and 2335 work places [2]. Across the country business incubators are uneven. In Kyiv and Kyiv region there are 12 business incubators, in Odessa region there are 9 incubators; 18 of 27 regions have 1 or 2 business incubators [3].

Let's consider the mechanism of creation and functioning of business incubators in detail.

Firstly it is elected strategy of business incubator that based on its development concept. It includes:

- choice of potential client firms;
- identifying the candidate companies;
- determining specialization of business incubator based on potential services and election of the industry. Nevertheless business incubator should provide innovative services.

The selection of future incubated firms includes the originality of their proposed scientific ideas, perspectives of their results, and selected areas of innovation. The point is that small firms can create innovative products or test them, or engage in replication of the latest developments.

Selected firms should be classified. The main principles for it are location of the company, number of employees, the level of logistical support, the amount of financial resources, sales and so on.

The needs of newborn companies depend on the type of activity, their opportunities and the requirements of the market environment. Business incubator determines the scale of the needs and correlates with the services that can be provided. Here the business incubator specializing, the cost of services and guarantees for funds return are important. Providing facilities, information, education, marketing are the most considerable services.

Than the business incubator plan should be created. It takes into account the stages of the client firm development. These steps include:

1) selection of client firm and placement for it in rent;

2) accommodation and adaptation of firm-beginner and providing services for it for short term (1 year);

3) the gradual growth of the company, increasing its level in the field of business innovation, reducing the list of providing services (2-3 years);

4) output from the incubator.

The business plan defines the basic parameters and directions of business incubator. It takes into account the number of firms that entered the incubator, the business activities of the incubator, financial and material resources, and the degree of support for companies in incubator, the principles and conditions for interaction between business incubator and firms after their exit.

Preferential conditions in business incubator exist for adapting small firms to requirements of the market environment. Firstly the newborn-company uses business incubator almost free. But while ii is growing and gaining the necessary knowledge business incubator reduces the amount of benefits and services.

The impact of business incubator is measured by various indicators. They include the number of innovative firms that were created by business incubator, the enterprises that "survived" after leaving it, the number of innovative projects, the volume of scientific and technical products, the number of created work places, the amount of the production and service squares etc.

Business incubator revenues usually consist of rent; fees for provided services, and profit of firms that left the incubator. The companies-beginners cannot pay large sums of money to obtain services and facilities during their formation. Therefore, the main source of income for the business incubator is gains from cooperation with former clients.

It should be noted that today in Ukraine business incubators have significant financial difficulties. Lack of funds leads to decrease in their activity. Usually incubators simply turn to counseling centers. Often they have dealt with their innovative value and begin to deal with problems for companies.

According to international experience, one of the most successful ways of developing and supporting business is a business support or business entity. It usually helps to simplify, facilitate and accelerate entry into the market and achieve desired business effect. Support, which provides incubation, helps beginners to overcome market barriers at an early stage of development. Statistically about a third of independently created firms survive. And over 85% of participants who used support of business incubators tend to become successful.

Business incubators are structures that assist new companies during their organization and development. The main objective of business incubators in the interactive process: to inspire people to organize their own business, create conditions for new companies, and to support them in developing innovative products etc. The main emphasis in the activities of business incubators is to stimulate the development of local and regional economics and creating work places. Business incubators are necessary for the promotion and development of beginner businesses. The role of business incubators is very important to ensure that local social and economic development especially in countries with low dynamic business development [3].

The purpose of a business incubator is providing favorable organizational and economic conditions for small and medium business, improving the competitiveness of enterprises and companies in the market by providing comprehensive assistance to entrepreneurs at all stages of organization and operation of enterprises [16, p . 64].

On the basis of the business – incubator experience in countries with developed economies, we have created a business – incubator model. It can help to to develop small business. It also includes: a block of innovation support; a block of marketing providing; a revenue block from consulting, legal and auditing services, leasing, publishing; a learning block.

Business incubators play an important role in the innovation infrastructure, because they are considered a part of the infrastructure. But they also are a tool for economic, social, structural and innovation policy. Business incubators can be as independent economic organizations that are created to support non-technological small business. They also can exist in a warehouse industrial park and be oriented in the field of high technologies. Incubator as the shape and element of innovation infrastructure is in constant development [17, p. 163].

One of the fundamental issues in the activities of business incubators is choosing optimal forms of created business incubators. At the present moment there is a great variety of legal forms of business incubators. Business incubators are structural units of a high order and as autonomous institutions. The legal form of business incubators (BI) largely determines potential sources of incubator funding. BI registration as a non-profit structure provides additional opportunities to obtain grants and funds to support small business innovation. The form of state, regional or lower subordinate institutions provides access to funding, participation in national and regional development programs small businesses. In turn, the legal form of the incubator depends on whom and on whose funds BI is generated.

The main advantage of a business incubator for entrepreneurs with financial difficulties is that incubators provide them "roof over their heads" on favorable terms, (at least for first time).

For business activities incubator should have the necessary facilities (based on international experience – 1000-2000 sq. m.), logistics (office equipment, Internet, classrooms, conference room, library), qualified staff, counselors and teachers generally work on a contract basis. [6]

The concept of a business incubator involves rotation of firms. So the incubator usually should not have long-term or pre-term rental agreement. The term of "life" in the incubator is from 2 to 5 years. If the company firmly stands on its feet during this time, it should find a space outside the incubator and leave space for new young company. However, in practice, depending on the current available space and demand for it sometimes longer contracts can be used.

**Conclusions.** Company's selection for business incubator should be carried out on a competitive basis. In this case, the applicant must prove that his project has a real chance for success according different criteria (education, experience, etc.).

Important advantages of a business incubator is also a creative atmosphere and the opportunity to communicate with other firms, the image of a serious company, flexible management in an incubator.

**References**


1. Amosha, O.I., Buleev, I.P., and Shevtsova G.Z. (2007) "Innovative updating of techno-technological base of industrial production on a synergetic basis: theory and practice", *Ekonomika promyslovosty*, vol.1, p. 3-9.

2. Andreev, V.O. (2008) "Results of the Business Incubator Development Program in Ukraine", *Rozvytok naukovo-teknologichnyh parkiv ta naukovyh struktur inshyh typiv: Materialy mizhnarodnoi naukovo-praktychnoi konferentsii* [Development of scientific and technological parks and innovative structures of other types: Materials of the International Scientific and Practical Conference], Lviv, 3-5.11.2002, pp. 41-46.

3. Business Incubation and Innovation Centers: Modern Technologies for Entrepreneurship Support and Innovative Economy Development, available at: http://www.academia.org.ua/?p = 326 (access November 5, 2017).

4. Vasilyeva, L.M. (2010) "Business incubators as part of small business support infrastructure", *Derzhava ta reginy*, vol. 1, pp. 50-54

5. Galitsa, I. (2009) "State regulation in the conditions of market relations", *Ekonomika Ukrainy*, vol. 6, pp. 52-53.

6. Gatash, V. (2017) "A business incubator for small and medium-sized innovation firms", available at: zn.kiev.ua (access November 5, 2017).

7. Goncharov, V.M., and Derechynsky, Yu.N. (2009) *Formuvannya organizatsiino-ekonomichnogo mechanizmu systemy innovatsiinogo rozvytku regionu* [Formation of organizational and economic mechanism of the system of innovative development of enterprises of the region], SPD Kupriyanov VS, Donetsk, Ukraine.

8. Zhuk, M.V. (2008) "Prerequisites for the formation of a national innovation system for accelerating economic development", *Aktualni problemy ekonomiki*, vol. 7, pp. 30-37.

9. Zhuk, M.V., and Borodina, O.M. (2008) "Infrastructure Provision of Innovation Process in Ukraine", *Aktualni problemy ekonomiki*, vol. 8, pp. 66-71.

10. The Law of Ukraine "On State Support to Small Entrepreneurship" dated 19.10.2000, No. 2063-III.

11. Law of Ukraine "On the National Program for Promotion of Small Business Development in Ukraine" dated 19.10.2000, No. 2063-III.

12. Zyanko, V.V. (2005) *Innovatsiine pidpriemntatvo v Ukraini: problemy stanovlennya ta rozvytku* [Innovative entrepreneurship in Ukraine: problems of formation and development], UNIVERSUM, Vinnytsya, Ukraine.

13. Kopchenko, I.M. (2009) "Actual problems of state support of small business of Ukraine at the present stage", *Formuvannya rynkovyh vidnosyn v Ukraini*, vol.4 (35), pp. 115 - 119.

14. Kopchenko, I.M. (2008) "State Support to the Development of Infrastructure for Supporting Small Entrepreneurship in Ukraine", *Aktualni problemy ekonomiki*, vol. 4, pp. 89-96.

15. Litvin, V.V. (2010) "The mechanism of state support for the development of small business in Ukraine", *Visnyk Donetskogo derzhavnogo universytetu ekonomiki ta torgivli*, vol. 5, pp. 36 - 43.

16. Matviychyk-Soskina, N. (2008) "Praktyka diyalnosti biznes inkubatoriv na bazi informatsiinyh tehnologii", [The practice of business incubator activity on the basis of information technologies: the experience of European countries], Institute for the Transformation of Society, Kyiv, Ukraine.

17. Nikitauk, O.P. (2009) "Business incubators in the system of financial support of small business", Svit finansiv, vol. 2 (3), pp. 160-164.

18. "Proposals for the Regional Target Program for the creation of innovation infrastructure in Odessa Oblast for 2009-2013", available at: http://www.oda.odessa.gov.ua/Web_oda/innovac_infrastr/propositions.doc (access November 5, 2017).

# OPTIMIZATION OF CUSTOMS PROCEDURES IN THE SOUTH CAUCASUS TRANSPORT CORIDOR

## ОПТИМИЗАЦИЯ ТАМОЖЕННЫХ ПРОЦЕДУР В ТРАНСПОРТНОМ КОРИДОРЕ ЮЖНОГО КАВКАЗА

Prof. Dr. T. Kochadze[1], Prof. Dr. R. Mamuladze[2], Doctoral candidate A. Gudadze[1] ,
1 AkakiTsereteli state University - Kutaisi, Georgia
2 Batumi State Maritime Academy – Batumi, Georgia
E-mail: temko1954@mail.ru , r.mamuladze@bsma.edu.ge, predatori.ag@gmail.com

***Abstract.*** *The rational use of convenient geographical location, the organized transport-communication and customs-logistics infrastructure, is the key for any country's integration into the world economy and the expansion of foreign economic ties.*

*The South Caucasus transport corridor connecting the Asian and European markets, has an important strategic role in the trade-economic context of East-West relations.*

*Today the formation of a common control of customs and signing between the countries of the South Caucasus is one of the priority tasks, which will facilitate harmonization of transit procedures in the region*

***KEYWORDS:*** *SILK ROAD; TRANSPORT CORIDOR; CUSTOMS CONTROL OF THE TRANZIT.*

## *1.Introduction*

Contemporary globalization is a qualitatively new phenomenon of world development that covers all areas of public life. The reconciliation of national and global-economic relations is exactly what is characteristic to globalization. Due to globalization development, the leading, priority role of international economic relations is increasing – today, it is very important to develop a single rule for the world economic systems and introduce it in the economy of each country, but this process is quite complex, and even the economic systems of powerful countries are hardly adapted to the challenges of the global economy [1].

The sustainable use of the advantageous geographical location, expansion of the frontiers of national markets, well-organized transport-communication and customs-logistics infrastructure, the creation of favorable conditions of export-import and transit operations, are significant factors for any country to integrate into the global economy and expand the liinternational economic relations [1,2].

International transport corridors fulfil at least two tasks: the first, they create the fundamental premise of involving in a single economic and cultural space of large area; the second, under conditions of deepening the globalization processes, for the macroeconomic regions, which are characterized by the fragmented nature of production forces in all fields of production and services, international transport corridors make up the uniform, economically far more efficient transport and logistics systems, for the rational exchange of the means of production and products [2].

The South Caucasus, as an energy-intensive region and transport corridor linking the markets of Asia and Europe, has long played an important strategic role in the trade, economic and political context of East-West relations.

In addition to significant energy load, the corridor's transport-transit function also takes a particular form that makes its content more valuable and more intensive. Accordingly, both its economic and geopolitical significances are increased. These include the Baku-Tbilisi-Kars railway line, whose transport-transit potential is of great interest not only to countries involved in the project and their partner countries in Central Asia and Europe, but also to more distant countries, particularly China and Afghanistan, as well as the United States of America.

Uzbekistan and Turkmenistan, whose future plans are largely related to the implementation of the Navoi-Turkmenbashi-Baku-Tbilisi-Kars transport project, which can provide their products with a much broader access to the European markets, are interested in using the potential of the China-Central Asia-South Caucasus-Turkey transport corridor [3].

The Baku-Tbilisi-Kars new railway transport corridor, which will unify the railway lines of Azerbaijan, Georgia and Turkey, is an important challenge for meeting the growing demand for trade flows existing between Europe, Caspian Region, Central Asia and China, as well as for the formation and improvement of the relevant transport corridor [4].

## *2. Preconditions and means for resolving the Problem*

The desire to use the transit potential of the South Caucasus Transport Corridor for their own benefit has also Afghanistan, which is deeply interested in opening an alternative corridor of roads leading to Iran and Pakistan. And the railroad line passing through the Central Asia and the South Caucasus, particularly, via Turkmenistan, Azerbaijan, Georgia and Turkey, is what is considered by it to be such a corridor, which will provide it with access to the Black Sea. It is only also natural that this project has a lot of support in the United States. Due to this, in November 2017, in Ashkhabad, there was signed an agreement on the establishment of a new Lapis Lazuli

transport corridor from Afghanistan to Europe crossing the territories of Turkmenistan and South Caucasus. The document was signed by representatives of the countries involved in the project - Afghanistan, Turkmenistan, Azerbaijan, Georgia and Turkey. The Agreement envisages the promotion of transport relations between the countries involved in the project, which involves fostering the smooth movement of goods and passengers, harmonization of administrative issues and customs procedures related to transit movement, and so on. [5].

In 2016, the lifting of sanctions on Iran has created the needs for the launch of the North-South Transport Corridor, which will naturally increase the transit potential of the South Caucasus. The Georgian side is interested in joining the Mumbai-Bandar Abbas Transport Corridor, which implies the rapid shipment of cargo through from the Mumbai port, crossing through the territories of Iran, Azerbaijan and Georgia using the ports of Poti and Batumi.

According to the agreement between Russia and Georgia, the transport corridors passing through the territory of Abkhazia and South Ossetia will be put into operation in the nearest future, which is a part of the North-South Corridor and links countries of South-West Asia (mainly Iran and India) to countries of Northern Europe. This will, in turn, facilitate the increase of cargo traffic flows and improving the capacity of transit traffic.

Trade-economic relations between Europe and Asia and more economic integration contribute significantly to the "Silk Road" direction, which is now considered to be the economic corridor with the greatest potential. Within the framework of the "Silk Road" development, great importance is attached to close cooperation between Georgia, Turkey and Azerbaijan in the field of transport and logistics.

Due to the favorable geopolitical situation and the location between the several major international and regional transport corridors (TRACECA, North-South, Lapis lazuli, a new silk road "One Belt and One Road"), Georgia and other South Caucasus states represent an integrating link between two macroeconomic continents - Europe and Asia, which provides movement of goods by the shortest route with a minimum amount of time [6]

Experts forecast that by 2020, the total volume of transit traffic through the territories of the South Caucasus countries is expected to increase. At the same time, according to experts, only half from the transit potential of the South Caucasus transport corridor is currently utilized.

The main direction of the development of the customs regulation mechanism of Georgia's international trade is, first of all, the improvement of the customs transit procedures and technologies.

Despite the fact that in Georgia has a number of measures have been taken aiming at improving the customs legislation and procedures: the modern customs registration centers – registration economic zones (REZ) have been built and put into operation, the cargo and vehicles registration procedures have been simplified, the prior declaration mechanisms have been introduced, thus redicing considerably the costs and time for registration, there are still a number of barriers that affect the shipping companies.

Recently, the loss of competitiveness of the South Caucasus Transport Corridor has resulted in redirecting transit traffic flows to alternative routes, which is due to a number of reasons, as follows [7]:

- Different tariff policies between the countries of the Caucasus, and high tariffs for transportation.
- Inadequate and ineffective infrastructure. For example, complicated geographical sections, where the road transport infrastructure is characterized by low throughput; sea ports, which that cannot accommodate large vessels.
- Low level of logistics development. Logistics companies cannot ensure improvement of services and provide comprehensive logistics services.
- Different customs legislation in the countries of the South Caucasus, when there is no uniform customs policy for control of goods and vehicles, and the shipping companies encounter different customs regulations when crossing the border.
- The lack of effective information technology, which significantly hinders the exchange of comprehensive information on transit goods between the customs authorities in each country, which negatively affect the time required for customs registration.

The lack of bilateral coordination in this regard, and the policy of ensuring the "sovereignty" of institutional information from regulatory bodies inevitably lead to the the cardinal differences existing in customs transit control systems, complicating their interactions that are required for the establishment of a single economic space, which significantly hinders the effective utilization of a high transit potential of the South Caucasus.

Formulation of common approaches to the customs control and clearance within the framework of the economic cooperation between the countries of the South Caucasus, is one of the priority tasks, which will facilitate the harmonization of transit procedures in the region; in addition, it creates the possibility of the realization of the attributes information technology of customs clearance and control. Full use of the transit potential of the South Caucasus countries based on information and communication technologies is possible through the integration into the electronic information system within the framework of customs cooperation, as well as by organizing information exchange by the customs authorities in each participating country with other countries and allies.

One of the most important directions in the reduction of administrative barriers, while performing transit operations, is the improvement of customs regulatory mechanisms of foreign economic activity. Inadequacy of customs control procedures and technologies, agencies and State interaction in customs checkpoints reduces the transit potential, contributes to an increase in financial expenditure at border crossings.

Effective utilization of the country's transit potential by customs authorities should be carried out within the framework of interconnected and contradictory transformation processes, of which the main ones are:

- Substantial modification of the rules for the functioning of customs authorities in close connection with the creation of a union similar to a customs union of Georgia, Azerbaijan, Turkey and Armenia (if only for promoting the customs transit and transit cargo movement), which will be associated with reduction or cancellation of the certain customs and other types of control procedures, within the borders of this Union.

- Formulation of the development strategy of the South Caucasus economic space, including the creation of an integrated transport, customs and logistics network, and development of the international transport corridor infrastructure crossing through the territories of the countries of the South Caucasus.
- Enhancing the coordination between customs authorities of the bordering states, and providing the exchange of information on goods and vehicles, control objects and also exchange of information about phyto-veterinarian sanitary products.
- Providing the customs authorities with technical and information equipment, which implies the use of modern technological systems and technical means of customs control.

## *3. Conclusion*

Within the framework of economic cooperation between the states of the Caucasus, the creation of a single automated information system for the customs control of transit is necessary for the exchange of information on goods and vehicles in real time.

The implementation of these approaches will facilitate the effective utilization of transit potential of the South Caucasus Transport Corridor, integration of the state in the region into the European transit system, as well as the creation of favorable conditions for involving the additional volumes international trade flows.

## *4. References*


1. Solomon Pavliashvili. Developmental characteristics of Georgia, as a transport corridor. 2014 – www.for.ge/view.php?for_id=29994&cat=1;
2. Zhukov E.A. Жуков, Е. А. The conceptual framework for establishing a single world transport system // Bulletin of International Nobel Economic Forum. — 2012.
3. Otar Turabelidze. From Asia to Europe, passing through the Caucasus. 2012 – www.opentext.org.ge/index.php?m=12&y=2012&art=9650
4. The statement made by the President of Georgia in the city of Kars on the ceremony of laying the foundations of the trans-Anatolian Gas Pipeline (TANAP). 2015 - www.president.gov.ge/ka-GE/pressamsakhuri/siakhleebi/
5. Georgia has signed the Agreement on establishing the Lapis Lazuli Transit Corridor. 2017 - www.ipress.ge/new/91844-saqartvelom-4-qveyanastan-ertad-satranzito-derefnis-lapis-lazulis-shetankhmebas-moatsera-kheli
6. S.A. Khapilin. Resumption of the integration processes within a customs union: transit potential development. 2014.
7. J. Tarimanashvili. Transit potential of Georgia: problems and prospects. 2017 - https://pia.ge/post/152483-saqartvelos-satranzito-potenciali-problemebi-da-perspeqtivebi



- ***Funding: This work was supported by Shota Rustaveli Georgian National Science Foundation (SRNSFG) [DP 2016_5. Organization and management of transport processes].***

# REVIEW AND ANALYSIS OF CURRENT AND PROJECTED NPPS IN EASTERN EUROPE

## ПРЕГЛЕД И АНАЛИЗ НА ДЕЙСТВАЩИТЕ И ПРОЕКТИРАНИТЕ АЕЦ В ИЗТОЧНА ЕВРОПА

Chief Assistant Professor PhD eng. Dolchinkov N. T.,
National Military University „Vasil Levski“, Veliko Tarnovo, Bulgaria,
National Research University "Moscow Power Engineering Institute", Moscow, Russia
n_dolchinkov@abv.bg

***Abstract:*** *All nuclear power plants in a 1000 km radius of Bulgaria have been napped. Huir power output the number of reactors and type indicated, as well as the fuel usefl and the storage of the processed fuel. An efficiency ingnity was conducted as well as political inporteence and local safety.*

**KEYWORDS:** *NPP, RADIATION CONTROL, IONIZING SOURCES, ATOMIC ENERGY, NUCLEAR POWER, GAMMA BACKGROUND*

### *1. Introduction*

With regard to the nuclear power stations located near Bulgaria, we will look at the sites that would have an impact on the change of the radiation gamma background on the territory of our country. We will also consider the possible new nuclear power plants near our border and sites where nuclear installations could be located.

Bulgaria borders directly with Greece and Turkey to the south, Macedonia and Serbia to the west, Romania to the north and the Black Sea to the east.

In our southern neighbor, Greece has no nuclear power and it is not foreseen to build such facilities in the foreseeable future. It is not known to have operating accelerators or other sources of ionizing radiation in an area 100 kilometers from our border. There are sources of radiation in medical institutions in 3 cities - Thessaloniki, Alexandroupolis and Kavala, located in northern Greece, which can not influence the radiation background in our territory due to their small power and the type of ionizing radiation used in them. In industry and mainly in the food sector, such sources are not used for different purposes. There are no vessels in the adjacent Aegean Sea where there are sources of ionizing radiation present and those in which a nuclear reaction could normally occur. The Army of Greece does not have weapons that would, after use, alter normal atmospheric parameters. In the bases of Greek territory, where troops from other countries (US) are located, there are no nuclear-weapon based weapons.

Similarly to Greece and our Sister Macedonia, there are no nuclear power plants, other types of nuclear reactors or accelerators where significant amounts of ionizing radiation can be emitted. In the field of economy and technology, there are no enterprises and institutes that are potentially dangerous to increase the radioactive background on the territory of Bulgaria as a result of a possible accident. Sources of ionizing radiation with a small dose are located in the hospitals "Ajabadem" and two more in Skopje, which are used for medical purposes. The Macedonian Army does not have nuclear weapons or the like. There are no weapons of mass destruction on the territory of Macedonia that would increase the radioactive background after use.

Our other western neighbor, Serbia, also does not pose a threat to our safety from the point of view of radiation protection. Near the Bulgarian borders there are no industrial sites that use sources of ionizing radiation with medium and large doses of load. Due to the country's specificity and the lack of large settlements in the eastern regions of the country, there are also large medical diagnostic and health establishments in which to use equipment with significant exposure power. Industrial and medical facilities that have sources of ionizing radiation with moderate and higher exposure are located in Belgrade or cities located far from the Bulgarian border and practically in case of a possible accident they would very hardly have an impact on the radiation situation in our country. The Serbian army does not have nuclear weapons and there are no such weapons in the territory of Serbia. There is an agreement between Serbia and Russia on mutual assistance and, if necessary, Russia can supply such a weapon on Serbian territory. In practice, this is very difficult to achieve in the current international environment because neighboring countries will not open their airspace for such supplies.

### *2. Sources of ionizing sources*

The Serbian side was interested in the Belene project, where it wanted to finance part of the construction against a corresponding shareholding in the plant. In this way, it wanted to provide electricity for itself and eventually to participate in the regional electricity market. Serbia's current process of development has not commented on its involvement in restarting the project [1].

The closest sites potentially hazardous to radioactive contamination following an accident and located west of us are Pakistani NPP in Hungary and Krusno NPP on the border between Slovenia and Croatia. Taking into account their location, their remoteness from Bulgaria, the prevailing winds and the EURDEP system, we can exclude them from the analysis and ignore their impact.

These are the countries and sites that pose a very minor threat to a possible nuclear accident and consequently change the natural radioactive background over Bulgaria. In the analysis of the state of NASCRRF and the available points in the vicinity of these countries, I believe that the system is fully in line with modern requirements and the international environment. As a result of research into sites in Greece, Macedonia and Serbia, which are sources of ionizing radiation in the development, we exclude a possible danger of radioactive contamination from these sources.

There is a significant difference in the possible threat from our other border regions and neighboring territories.

In our northern neighbor, Romania has a "Black Water" NPP, which is located on the Danube River 60 km after Silistra and about 40-50 km by air from its state border. The first reactor was built jointly by the Canadian company Atomic Energy of Canada Limited, and Ansaldo, Italy, and was put into operation on 2 December 1996. It is constructed using CANDU technology and has a capacity of 620 MW. The second reactor was put into operation in 2007 and is of the same type. The project to build a third and fourth reactor of Romania's nuclear power plant "Cherna Voda" is part of Romania's energy strategy, as more than one billion euros have been invested in this project, Energy Minister Victor Grigorescu said in 2016, quoted by "Adjuster". Grigorescu pointed out that nuclear power is one of the sources by which the country's energy security is strengthened. In his words, the project also makes sense in terms of reducing the use of coal for electricity production, as currently 30% of Romania's electricity is generated by the TPP. Romanian President Klaus Johanias also called the project for the expansion of the TPP water "" priority investment "for the country.

The Romanian State Energy Company (SNN) and China's General Electric Nuclear Power Corp. (CGN) signed on November 9, 2015, a Memorandum of Understanding on the design, construction, operation and decommissioning of third and the fourth

unit of the NPP "Cherna Voda". The agreement is the basis for a joint project company, in which no less than 51 percent will belong to CGN, SNN said.

The signed Memorandum forms part of the state strategy of selecting the investor of the project and defines the "direction of the future cooperation" between the parties. "SN Nuclearelectrica SA" and "China General Nuclear Power Corp." reached the final stage of the investor selection procedure launched in August 2014 and start discussing the investment agreement and the founding agreement of the new project company, the SNN .

On both 700 MW units of the second stage of the Cernavoda NPP will be installed CANDU 6 heavy water reactors similar to those of the first and second power units.

Specialists are alarmed by the fact that part of the equipment is obsolete, not renewed, and the work teams are not sufficiently prepared. Part of the staff serving nodal points has left in the past 2 years and works at other nuclear sites in Europe for higher pay. The headquarters in Romania were verified by the International Agency for the Use of Atomic Energy for Peaceful Purposes under the OSART Safe Operation Program from 7 to 24 November. The mission was second for the Romanian headquarters and covered 10 areas: management and leadership, training and qualification, operation, repair, technical support, exploitation experience feedback, radiation protection, chemistry, emergency preparedness and severe accident management. to establish the level of safety at individual nuclear power plants and apply to the IAEA worldwide. The new element in controls - related to the management of severe accidents, was introduced after the events at Fukushima NPP in 2011. In accordance with IAEA rules, the mission has completed a report with described recommendations and good practices, which, after being endorsed by the International Agency, will be publicly available to the public.

The uncertainty in the project to complete the new 2 blocks, the outflow of a number of Western investors from the project conceals it with unpredictability and ambiguity, similar to our Belene project. The fact is that in 2014 the plant was forced to stop 6 times, and in 2015 - 4 times. The location of the Chernapa NPP and the prevailing winds in the area, according to NIMH data for the past 5 years, make it a serious potential pollutant of Northeastern Bulgaria in the event of a nuclear accident.

The Black Sea port of Constanta has developed very fast over the last decade. In addition to its commercial significance, it is becoming more and more of military significance, and many NATO navy ships have been moored there. The American Karneys, equipped with an Aegis Information System ("Idys"), was at the end of 2016 in the Romanian Constanta harbor. The permanent base of Carney and the other American ships is the Spanish port of Rota. Carney is armed with steerable rockets. Along with the rosters, Porter and Donald Cook, as well as the Ground Anti-Rocket (DE) in Romania and Poland, also equipped with the IGIS system, they are parts of the European segment of the US PRO. The Montreux Convention in 1936 limits the stay of the warships of non-Black Sea states in the Black Sea to 21 days. That's why the rockets of these military craft are being made.

The presence of the Cherna Voda NPP and the increased shipping and the use of the port in Constanta are alarming as potential contributors to the increase of the natural radioactive background in the region of North-East Bulgaria. This necessitates possible changes and optimization of NASCRTF in this area.

In the central part of Southern Romania, about 40 km north of the Bulgarian border, in the village of Zagradzhden, Pleven district, is the former Air Force Airport of Romania to the village of Deveselo. Since mid-2016, there has been a US base, which is part of NATO's anti-missile defense strategy. So NATO should receive 24/7 protection, integrated with US radar and anti-missile systems, already deployed in Mediterranean sea.

In place of Romania's former Air Force base, there are 24 SM-3 missiles and Aegis system radar. The Aegis Ashore "Terminal Shield" system includes powerful radar, interceptors and a communications system. It is the first of its kind in Europe. The shield will be fully integrated into NATO's wider defense system against ballistic missiles from potential enemies.

There is a serious concern and the public opinion of military scientists on the transfer of 20 atomic missile missiles from the Inzhirlik base (Turkey) to this Romanian base. Following the attempted coup in Turkey in the summer of 2016, and the recent events, talked about the security of the large American base and the weapons located there. Relations between the United States and Turkey were severely tightened, and in view of Turkey's request for extradition to 78-year-old Islamic preacher Fethullah Gullen, who lives in the United States and is accused by Turkey of organizing the failed coup on July 15, 2016. The unpredictability of Turkish President Recep Tayyip Erdogan is a prerequisite for these views of military strategy specialists.

But the presence of nuclear-powered missiles at 40 km from the Bulgarian border can not leave us indifferent to them and their storage. Despite good relations with Romania and NATO's partnership in such developments, we must take care of our radiation security and be prepared to deploy another point of the NASCRPF system to monitor the radiation background in the Zagrazhden and Gigen villages . This point would also be effective in terms of restarting the Belene project.

Although we do not have a land border in the east, we can not be calm about the events that happen in the Black Sea. Over the past 5 years, we have an increased presence of military equipment, including one that has, or could have, nuclear-powered missiles. The reasons for the increased presence of such a technique can be summarized in:

• The expansion of the US and NATO missiles to the east;

• The military conflict between Ukraine and Russia, the problems in the Crimea and the military bases of Russia in the former Ukraine on the territory of the Crimea;

• The conflict in the Middle East, involving many countries in the region - Turkey, Russia, Syria, etc., as well as a large part of the Great Powers;

• The expansion of Terrorists from the Islamic State and other organizations close to it.

The presence of large vessels of Russia, the United States and NATO in the Black Sea, the continual lurking, the use of aviation and other actions continually escalate the situation near our state border. This leads to an upsurge in the situation, and a wrong move or action can cause undesirable consequences for us and the region.

In this direction we can optimize the control system by analyzing and adding, if necessary, 1-2 points, in addition to the available stations of Cape Kaliakra, Varna, Cape Emine and Ahtopol.

The last critical direction from the point of view of radiation security is our southeastern border and Turkey in particular. During the last year there have been significant political and economic changes. Turkish President Recep Tayyip Erdogan, following an unsuccessful coup attempt, made very great political changes in our southern neighbor. Relations with the United States have been greatly complicated, even in the military, where cooperation between the two countries was one of the best in the world. Even talk of ending the activities of the Inzhirlik military base - the largest US base in the Mediterranean.

After the freezing of relations between Russia and Turkey when the Su-24 bomber was shot down by Turkish fighters in the sky over Syria on 24 November 2015, there was a sharp warming in 2016 and a re-launch of many significant economic projects. The construction of the Akkuku nuclear power plant from Russia is restarted, and the construction of the Sinap NPP on the Black Sea coast from France and Japan soon begins. The Turkish president intends to start construction of a third nuclear power plant, one of the sites under consideration being located 20 kilometers south of Rezovo on the Black Sea coast. There is no decision yet to choose a site, but the Bulgarian side should carefully monitor closely the developments in the neighboring country.

Bearing in mind the unpredictability and decision-making nature of the Turkish Head of State, we should be prepared for

various actions on his part and ready-made options for action to preserve the radiation safety of Bulgaria.

This is not to neglect the refugee flow from Turkey to Bulgaria and its external regulation. In these masses, composed mostly of young men, can safely be transported through the unregulated places where they cross the state border and dangerous radioactive materials. They can then be used unlawfully to infect our or other territories and increase the radioactive background.

As a result of research on sources of ionizing radiation in Romania, the Black Sea and Turkey, we exclude small sources in medical institutions, industrial plants and institutes, and we need to focus on the "Black Water" Base in Deveselo, the Constanta port in Romania, military ships and the presence of large aircraft in the Black Sea and the potential new nuclear power plant in Turkey at this stage of development, and we should not lower our vigilance.

### *3. NPP*

Worldwide, 212 nuclear power plants with 438 reactor units in 31 countries currently operate - with a total installed capacity of 374,814 megawatts.

Next 64 with a total capacity of 62,754 MW are under construction, including 10, which have been under construction for more than 15 years.

125 reactor units with a total installed capacity of 37,794 MW were decommissioned for various reasons.

The first nuclear power plant was put into operation in the USSR on July 26, 1954.

The next one is in the UK (Calder Hall) - August 27, 1956.

Power "Kashiwazaki-Kariva" in Japan with 7 blocks and a total output of 8.200 MW is currently the most powerful in the world, and the two units of the plant "Civeaux" in France with an output of 1.561 MW each are the most powerful nuclear reactors in the world.




As of March 2017, 93 NPPs with 196 units and a capacity of 179,000 MW operate in Europe. They are building new 13 units with 14,000 MW. Out of operation, 84 units in 13 countries with a capacity of 26,000 MW have been decommissioned. They are located in 18 countries - Belgium, Bulgaria, Germany, Finland, France, Lithuania, Netherlands, Romania, Russia, Sweden, Switzerland, Slovakia, Slovenia, Spain, Czech Republic, Ukraine, Hungary and the UK.

NPP "Cherna Voda" is the only nuclear power plant in Romania. It is situated near the town of the same name along the Danube River, about 40 km after the end of the Bulgarian section of the river. It has two active power units with Canadian CANDU (CANADA Deuterium Uranium), with an electrical output of 700 MW each. The first reactor was put into operation in 1996 and the second reactor in 2007 was 18% of the electricity consumed in the country. The plant was designed by Canadian Atomic Energy of Canada Limited in the 1980s. Last year alone, the plant was shut down six times for technical reasons.

The project envisaged the construction of five power units. In 2015 -2016 another two blocks of the same type were planned to be put into operation, which would cost investors (seven Romanian and international companies) another 4 billion euros. Romanian nuclear power company Nuclearelectrica believes that by the end of the year, it will reach an agreement on the completion of the third and fourth units of the Chernapa NPP with the Chinese group "China General Newark Power Corporation", which was announced last fall the winner of the auction, organized by the Romanian state. Fifth block is still frozen

The electricity from the NPP in Slovakia is over 55% in the total energy balance. There are four units - two of the Bohunice NPP and two more of the Mohovce NPP - the reactors are WWER-440. All of them are built on a Russian project. In Slovakia, they are well aware of the quality of Russian nuclear technology.

Upon the entry of Slovakia into the European Union at "Bogunice" in 2006 and 2008 two blocks were stopped. They worked from 1984 and 1985. Then the country began to import electricity because a certain shortage arose. Hence, the desire to build a new block is completely logical. And the fact that Rosatom as a solid performer makes proposals on a legitimate basis is a normal business.

There are 2 NPPs with 4 reactors in the Czech Republic. Temelin NPP has two power units with Sovereign WWER-1000 reactors and an electric power of 1000 MW. The second Czech Dukovany NPP was built by Soviet specialists in the period 1974-1987. There are 4 units with reactors type BWLP-440 B-213.

Hungary operates the Paksch NPP, which has 4 VVER 440 units and produces about 40% of the country's electricity. It was built in 1980 and is the only nuclear plant in Hungary.

The decision to build two new reactors was taken by the Hungarian Parliament in 2009, but the announcement of a tender for the construction was postponed several times. Russian state-owned company Rosatom will finance and build two new nuclear units in the Hungarian Pakistani nuclear power plant, which will double the capacity of the plant. Apart from Rosatom, interest in the project was announced by Areva and Westinghouse.

Currently it has four active reactors with a total power of about 2GW and supplies 40% of the country's electricity. The new two reactors are expected to double the capacity of the plant.

KRUSKO NPP is a nuclear power plant located near the town of Krushko, Slovenia. The plant started operating on 15 January 1983. It was built on a project by Croatia and Slovenia, which at that time were Allied Republics in Yugoslavia. The planned date of termination of the plant is January 14, 2023.

Currently, only 1 reactor in the plant, which produces 730 MW of energy, is active. The owner of the headquarters is the mixed Slovenian-Croatian company Nuclear Electric Kruzko.

Slovenia plans to build a second block in Krško NPP and the proposal is part of the coalition agreement of Prime Minister Alenka Bratushek's government, MIA news agency reported.

It is envisaged for the construction of the new bloc to hold a referendum before the end of the regular mandate of the government, ie. by 2015.The referendum would cost between 3.5 and 4 billion euros. The construction of the second block is foreseen in the current Slovenian development plan until 2023, but the funding of the project is questionable.

To diversify its electricity supply and reduce its energy dependence on Russia or Iran, Turkey has launched an ambitious program that envisages the construction of three NPPs by 2030.

The first Turkish NPP will be built from Russia to the Mediterranean city of Mersin, in Acqueu. In April 2015 the first sod of the plant was made. The 19 billion-euro project will be carried out by the Russian company Rosatom, the plant being expected to come into operation in 2020. Reactors from the last three plus generation will be built to make it impossible to repeat the accident at the Japanese Fukushima NPP ".

Turkish Energy Minister Taner Yildiz and Rosatom Director Sergei Kiriyenko took part in Acqueu on the Mediterranean coast

in Mersin County in a ceremony for laying the first stone of the construction of the first of the four reactors each with a capacity of 1200 megawatts . Construction works will start in the middle of 2015. Electricity production is expected to start in 2020.

Besides the nuclear power plant in Akkuu, Turkey plans to build a second nuclear power plant in Synop County, on the Black Sea coast. This € 15 billion project was awarded in 2013 to a consortium comprising the Turkish company Euas, the Japanese companies Mitsubishi and Ithou and the French Jee de Suez. Mitsubishi Heavy Industries and Areva offer the jointly developed Atmea-1 reactor with a capacity of 1100 megawatts.

It is expected that the construction of the plant will begin in 2017 to put into operation the first part planned for 2023. According to rulers in Turkey by 2023, the electricity consumption there will increase more than 2 times and they choose for strategy the construction of 10-15 atomic reactors with a total power of more than 15 GW. One of the planned NPPs will be next to Bulgaria - about 15 km from Rezovo.

The idea of other nuclear fuel producers to deliver to Russian-made nuclear power plants was criticized by experts in Europe. This is written by the Russian agency RIA Novosti in its analysis. International experts point out that this may cause economic risks. Furthermore, there is no guarantee that the second manufacturer as a "mandatory supplier" will also offer favorable terms or provide fuel of a reliable quality.

The mandatory availability of alternative nuclear fuel suppliers for European NPP reactors built on Russian or Soviet projects is inappropriate for a number of reasons. These include economic and nuclear safety issues. Around this, the participants took part in a roundtable held at the 10th European Conference on Nuclear Energy, organized by Platts in Brussels.

Earlier, it was reported that European companies operating nuclear power plants with Russian WWER reactors must have at least two sources of nuclear fuel delivery. This scheme is supported by Westinghouse's US nuclear fuel producer. Earlier international experts have repeatedly noted that this position does not meet free and fair market relations, says RIA Novosti.

Round table participants also criticized the idea of diversifying nuclear fuel suppliers at all costs.

"There may be economic risks," one of the founders of Trusted Sources Christopher Grenville said. It's about consumers being interested in buying high-quality and proven fuel from a reliable supplier. And, at the same time, there is no guarantee that the second manufacturer as a "mandatory supplier" will offer such favorable terms or will deliver fuel of a reliable quality.

In addition, in the use of Russian (Soviet) third-party fuel reactors, risks may arise from the point of view of nuclear safety issues due to the technical differences between the fuel assemblies themselves and the fuel itself.

Ute Blom-Heber, a representative of the European Atomic Energy Community (EAEC), noted that the Agency does not insist on the necessity of two or more fuel suppliers. "This question must be solved by the plant operators themselves," Bloom-Heber said.

Despite the pressure from the United States, the European Union must necessarily diversify sources of nuclear fuel delivery to its Russian-designed nuclear power plants to break the Kremlin's energy dependence, so far, the idea remains in the political field rather than seeing it a real economic benefit and a guarantee of technical safety.

At the end of last year, a political agreement was reached on the revised Nuclear Safety Directive. "Nuclear safety is of paramount importance for all European citizens and we must make every effort to ensure that the highest safety standards in each EU nuclear plant are respected. officially accepted, will help ensure the continuous improvement of the safety of our nuclear installations, "said EU Commissioner Gunther Oettinger.

The revised Directive will strengthen the role and independence of national regulators and will help to increase transparency on nuclear safety issues. It will introduce a system of European peer reviews to be carried out at least once every ten years. It will also ensure that European nuclear safety rules are in line with the latest international standards.

## *4.Conclusions:*

1 In modern nuclear reactors with a high degree of safety, all radioactive substances are in closed systems and can be ejected out only in emergencies.
2. The role of nuclear energy, despite the negative attitudes and emergencies, does not decrease or even increase. Countries with increasing demand for electricity are targeting the use of nuclear power.
3. Measures shall be taken to increase the safety of the operation of the NPP and to take preventive measures to prevent accidents.
4. There is a hidden race and redistribution of the markets related to the servicing of the power plants and the supply of nuclear fuel, and in many cases the political situation shifts the observance of the measures for proper exploitation and compatibility of the products.

## *5.Literature:*


1. Косев К., Ретроспекция на ядрената енергетика в България, Енергетика (МЕЕР), София, 2002;
2. Dolchinkov N. T., N. B. Nichev, Characteristics of radiation, Revista academiei for ţelor terestre NR. 2 (82)/2016;
3. Dolchinkov N. T. , N. B. Nichev, Radiation background of the atmosphere, soil and water in Bulgaria and its monitoring in the contemporary political conditions,ISJ Security & future, №1/2017;
4. http://www.atominfo.bg;
5. https:www.//geopolitica.eu;
6. http://www.dnes.bg/eu;
7. http://www.eea.government.bg;

# GREEN CARBIDES - INNOVATION IN THERMAL SPRAYING COATINGS

Assoc. Prof. M.Sc. Guzanová A. PhD., Prof. M.Sc. Brezinová J. PhD., M.Sc. Landová M.
Faculty of Mechanical Engineering – Technical University of Košice, Slovak Republic
anna.guzanova@tuke.sk

***Abstract:*** *The paper presents results of research of the essential characteristics of two kinds of advanced coatings applied by HVOF technology. One studied coating: WB-WC-Co (60-30-10%) contains two types of hard particles (WC and WB), the second coating is eco-friendly alternative to the previously used WC-based coatings, called "green carbides" with the composition WC-FeCrAl (85-15%). In green carbides coating the heavy metals (Co, Ni, NiCr) forming the binding matrix in conventional wear-resistant coatings are replaced by more environmentally friendly matrix based on FeCrAl alloy. On the coatings was carried out: metallographic analysis, measurement of thickness, micro-hardness, adhesion, resistance to thermal cyclic loading and adhesive, abrasive and erosive wear resistance. There were also determined corrosion characteristics of the coatings in NaCl and SAR solutions.*

**Keywords**: HVOF TECHNOLOGY, ADHESION, WEAR, FRICTION COEFFICIENT, THERMAL LOADING, CORROSION RATE

## *1. Introduction*

The components of production machines in technical practice are stressed by various operating conditions (transmitted forces, pressures, temperature, environment, etc.). By the influence of these diverse effects, in the majority of machines and their components stresses occurs, which causes unwanted damage of the surface (wear, deformation, corrosion, cracks, fractures etc.). To avoid substantial damage of surfaces of machinery components, there have been developed various methods of forming protective layers, resistant to operating conditions. Thermal spraying technology also belongs to such methods. Coatings formed using thermal spraying technology for its high hardness and wear resistance even at higher operating temperatures are often applied in many fields of industry, especially in automotive, aerospace, energy, engineering, manufacturing and mining industry.

Recently, just cermet coatings containing hard WC particles in metallic matrix applied using HVOF (High Velocity Oxygen Fuel) technology was seen as a less dangerous and more environmentally friendly alternative to hard chrome plating [1]. Because the WC-based powders contain heavy metals such as Co and Ni [2-15], there is very strict logistics of powders used for coatings formation in the HVOF process. Currently, effort of materials scientists is focused on developing new powders, in which these elements in metallic matrix is eliminated and are replaced by other alloys. One of them is the powder WC-FeCrAl, called "green carbides".

The aim of the experiment was to evaluate the characteristics of the two types of coatings containing hard carbide particles in Co and also in Co-free matrix with respect to their tribological properties in atmosphere and in a corrosive environment [16-19].

## *2. Materials and Methods*

The base material for production of test samples was stainless steel AISI 316L. The test samples were of a cylindrical shape with a diameter of 25 mm and a length of 70 mm. The coatings were applied to the front area of the cylinder. Before powder spraying the base material was cleaned by abrasive blasting using white aluminum oxide with grain size of 0.56 mm, air pressure of 0.4 MPa, blasting angle of 90° and a blasting distance of 300 mm [20,21]. The coating was applied by HVOF technology using TAFA JP-5000 spraying system under spraying parameters recommended by the powder manufacturer.

Powders used:

WC-WB-Co (60/30/10), agglomerated and sintered, grain size +15/-45 µm, used for wear and corrosion protection in molten metal (for Zn bath rolls in Continuous Galvanizing Lines)

WC-FeCrAl (85/15), agglomerated and sintered, grain size +15/-45 µm, wear resistant coating with Ni- and Co-free metallic binder, replacement for WC-Co or WC-Ni

The structure and thickness of coatings were assessed on metallographic sections using light and electron microscopy. The microhardness was evaluated using test load 980,7 mN and dwell 15 s.

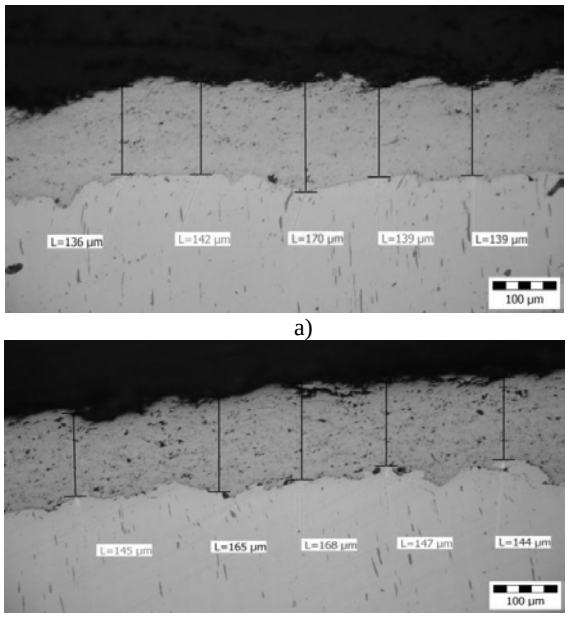
The coatings were evaluated as-sprayed and after 5 and 10 thermal cycles. One thermal cycle consisted of heating to 600 °C, dwell time of 20 min in furnace, followed by cooling to room temperature using still air.

Adhesion of coatings was determined by pull-off test (using 2K adhesive Loctite 9497) and wear resistance of coatings by pin-on-disc test (load 1.5 N, velocity 0.02 $m.s^{-1}$, duration of test 60 min, environment: atmosphere and immersion in 1 M NaCl solution, a static counterpart SiC ball, diameter 6 mm). Abrasive resistance was determined using abrasive belt (mesh 80 and 120, load 10 N, speed of abrasive 0.33 $m.s^{-1}$, wear track: 40 m) and dry erosion test in pin mill (abrasive: brown corundum, grain size: 1.2 mm, sample speed 1.74 mps, sample angle 45° and 90°, duration 8 hours).

Measurement of corrosion properties of coatings was realized by potentiodynamic test. Samples were exposed to 3.5% NaCl solution and SAR (simulated acid rain, pH=5) solution. Tests were performed on device Potentiostat SP 150(Bio-LOgic Science Instruments) and were processed using software EC-Lab V10. As the reference electrode was used saturated calomel electrode (SCE) and as an auxiliary electrode was used platinum electrode (Pt). The start of the measurement consisted of stabilizing the electrode potential Er [V] in time interval of 15 minutes. The software recorded values every 5 seconds or 5 mV. The polarization ranged from -0.30 V against the free potential, up to 1.00 V against the calomel electrode at polarization rate of 1 mV/s. After elapsing of the time sequence, the values most closely related to observed potential values were recorded. The resulting current densities depending on the inserted potential were plotted in semilogarithmic coordinates and analyzed by Tafel analysis.

## *3. Results and Discussion*

The thickness of the coatings was evaluated on several metallographic cross-sections. The cross-section of the coatings is shown in Fig. 1. There the thickness of the coatings can be seen.



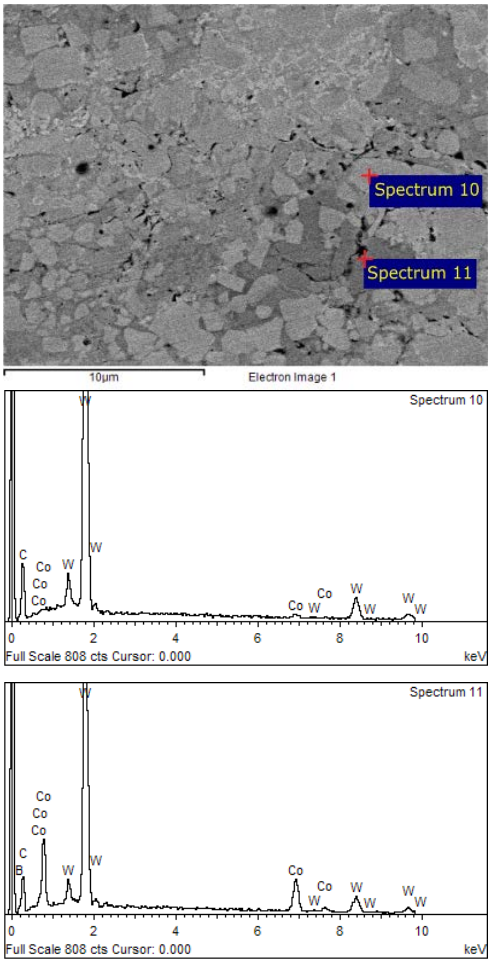

a)

b)

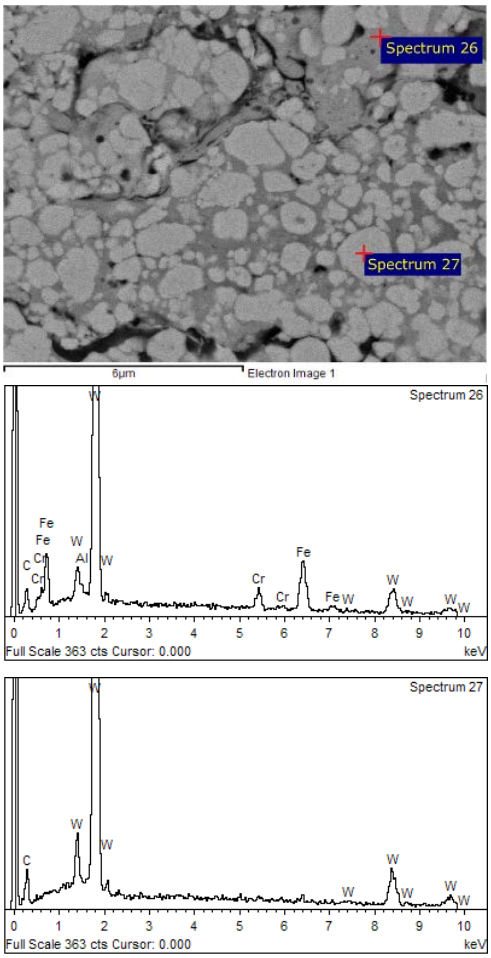
***Fig. 1*** *Metallography section of the coatings: a) WC-WB-Co, b) WC-FeCrAl, LM*

There is is a visible interface between the substrate and the coating in Fig. 1. The interface is indented, corresponding to profile of surface after grit blasting. The coating good fills all valleys in the surface, in the interface are not present any defects. The coatings are well anchored in surface irregularities. Average coatings thickness varies from 145 to 174 µm.

More detailed analyses of the structure of coatings were performed using SEM. The microstructure of the coating and EDX analyses of hard particles and matrix are showed in Fig. 2.




a)




b)

***Fig. 2*** *SEM image of the coatings: a) WC-WB-Co, b) WC-FeCrA*

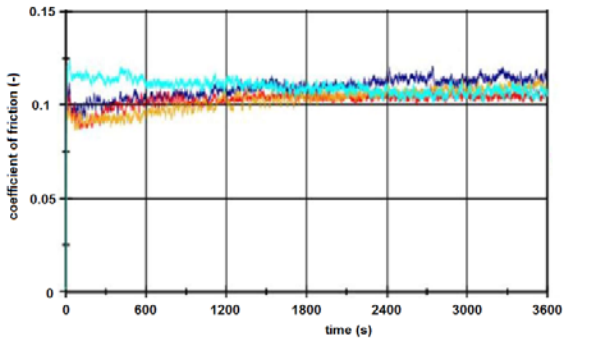
The coating WB-WC-Co consists of two types of hard particles (WC and WB) in soft binding Co matrix which ensures the coherence of carbides. The coating WC-FeCrAl contains hard particles of WC in a matrix based on FeCrAl alloy.

The hardness of the coating WC-WB-Co was found between 1200 and 1300 HV 0.1 and hardness of coating WC-FeCrAl between 1000 and 1100 HV 0.1. Adhesion of both coatings as sprayed, or after thermal cyclic loading exceeded the cohesive strength of the adhesive used (>50 MPa). The results of determination of thickness, hardness, and adhesion of coatings are summarized in Tab. 1.

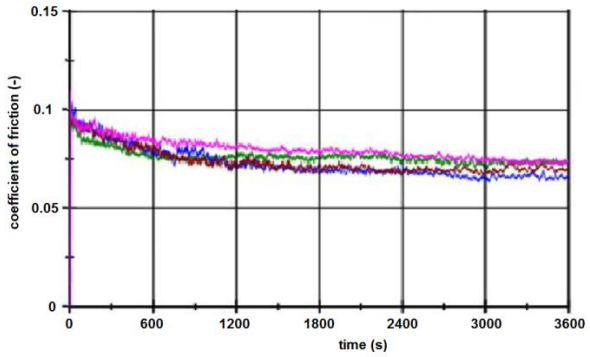
***Table 1:*** *Results of the tests*

| **WC-WB-Co** | | | |
|---|---|---|---|
| **Number of thermal cycles** | **0** | **5** | **10** |
| Thickness / µm | 145 | 151 | 160 |
| Hardness HV0.1 | 1303 | 1325 | 1229 |
| Adhesion / MPa | >56 | >51 | >50 |
| **WC-FeCrAl** | | | |
| Thickness / µm | 165 | 157 | 174 |
| Hardness HV0.1 | 1075 | 1050 | 1069 |
| Adhesion / MPa | >50 | >56 | >54 |

Wear resistance of coatings as-sprayed and after the thermal cycles was evaluated by pin-on-disc test under dry friction conditions in the atmosphere and also immersed in the NaCl solution. The course of the friction coefficient during pin-on-disc test states Fig. 3.



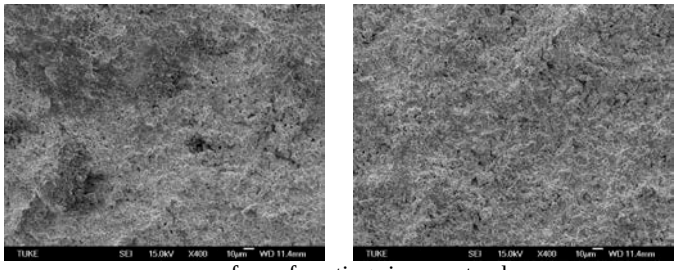

a)



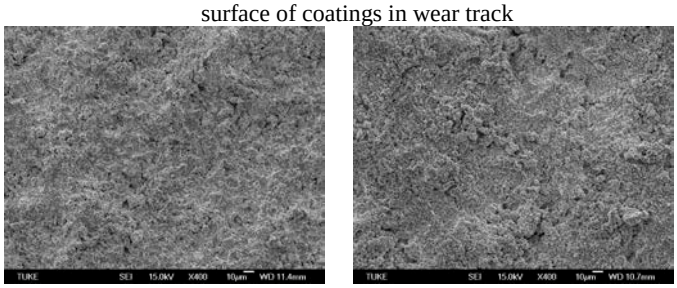

b)

***Fig. 3*** *Friction coefficient of the coatings after 5 and 10 thermal cycles in the atmosphere a) and in NaCl solution b)*

Friction coefficient of the coatings in the atmosphere after the initial start-up became stabilized slightly above a value of 0.1, and immersed in NaCl solution was stabilized slightly below 0.1. The appearance of the coatings surface in wear track and out of wear track is shown in Fig. 4.



surface of coatings in wear track



surface of coatings out of wear track

WC-WB-Co WC-FeCrAl

***Fig. 4*** *Surface of the coatings in wear track and out of wear track*

Weight loss of coatings after pin-on-disk test was minimal so could not be determined although the resolution of the balance was $1\times10^{-4}$ [g], as confirmed also appearance of wear track. Surface of coatings in wear track and out of wear the track is almost identical, they are visible no signs of particles removed from coating material. Conversely, on the static counterpart was found volume loss of material, Tab. 2.

From Fig. 5 can be stated that higher wear resistance showed the WC-WB-Co coating. Differences in weight loss using smaller abrasive grains (P120) were more pronounced. Smaller abrasive grain is closer to the size of WC, WC and WB particles and more intensively removes them compared to large abrasive grains.

***Table 2:*** *Wear of the balls in mm$^3$*

| Number of thermal cycles | ATM | | NaCl | |
|---|---|---|---|---|
| | 5 | 10 | 5 | 10 |
| **WC-WB-Co** | 0.03 | 0.04 | 0.04 | 0.06 |
| **WC-FeCrAl** | 0.05 | 0.04 | 0.02 | 0.05 |

Fig. 5 shows the weight loss of the coatings in abrasive wear test using abrasive cloth.

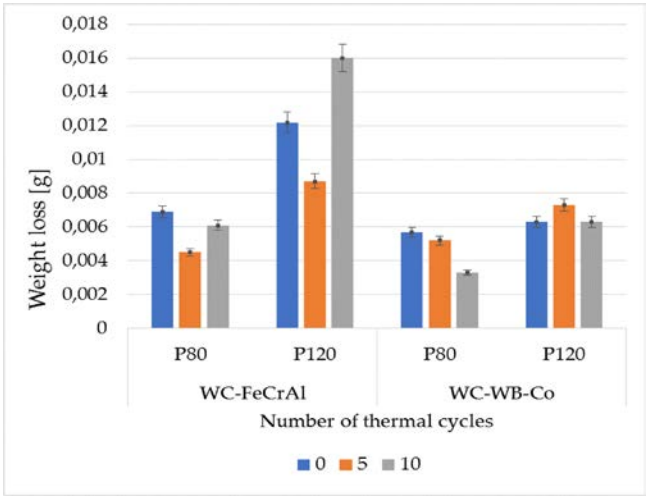



***Fig. 5*** *Weight loss of the coatings in dependence of abrasive cloth grain size*

Fig. 6 shows the weight loss of the coatings in dry erosion test in pin mill with sample angle of 45° and 90° depending on the number of thermal cycles.

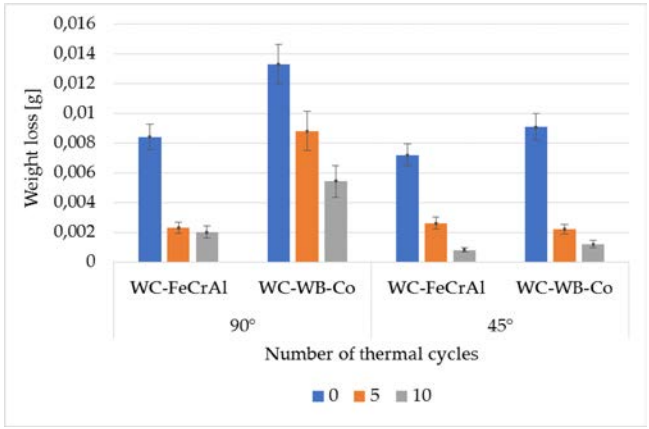



***Fig. 6*** *Weight loss of the coatings at particular sample angle*

The results show that the coatings exhibit very good resistance to erosive wear. Lower weight loss values were recorded for the WC-FeCrAl coating. Due to the thermal cycles, the weight loss decreased. The coatings exhibited higher wear at higher sample angles. Despite of hard erosive conditions, the weight loss of coatings was minimal. This is the manifestation of good adhesion of the coatings to the substrate, but especially between the particles and the matrix.

Using Tafel analysis of potentiodynamic polarizing curves the current densities of the measured samples and the calculated corrosion rate of the evaluated coatings were determined. The measured values of exposed samples in solution SAR and in solution 3.5% NaCl are shown in Tab. 3.

***Table 3:*** *Values of corrosion potential, current density, and slopes of cathode and anode dependence*

| | 3.5 % NaCl | | SAR | |
|---|---|---|---|---|
| | **WC-FeCrAl** | **WC-WB-Co** | **WC-FeCrAl** | **WC-WB-Co** |
| **$E_{corr}$ [mV]** | -432.876 | -582.858 | -276.291 | -532.463 |
| **$i_{corr}$ [µA]** | 18.561 | 18.735 | 6.328 | 7.71 |
| **$\beta_c$ [mV]** | 121.9 | 310.8 | 277.8 | 309.9 |
| **$\beta_a$ [mV]** | 193.2 | 149.8 | 309.8 | 350.4 |

Based on experimentally obtained results, we can conclude that the lowest current density was recorded on the WC-FeCrAl coating exposed in SAR solution. The highest current density was recorded on the WC-WB-Co coating exposed to 3.5% NaCl solution. Regarding solution used, higher corrosion aggressivity showed 3.5% NaCl solution compared to SAR. Higher corrosion resistance in both testing solutions showed WC-FeCrAl coating.

## *4. Conclusion*

Both coatings exhibited comparable properties as for thickness (140-170 µm), hardness (1300 and 1050 HV0.1), adhesion (> 50 MPa), and also in terms of adhesive, abrasive and erosive wear resistance (minimal weight loss, low friction coefficient: 0.1 in the atmosphere and also in NaCl solution). It can be concluded that "green carbides" coating is environmentally more friendly replacement for coatings containing Co and Ni without reducing the performance of the coating and with higher corrosion resistance compared to WC-WB-Co coating.

## *Acknowledgement*

This work was supported by the Ministry of Education, Science, Research and Sport of the Slovak Republic (VEGA 1/0424/17.

## *References*

1. Bolelli G. et al. (2012), Cermet coatings with Fe-based matrix as alternative to WC–CoCr: Mechanical and tribological behaviours, Surface and Coatings Technology, Vol. 206, No. 19-20, 4079–4094.
2. Brezinová J., Guzanová A., Draganovská D., Bronček J. (2015), Quality Evaluation of HVOF Coatings on the Basis of WC-Co in Tribocorrosive Conditions, Materials Science Forum, Vol. 811, 63-66.
3. Aw P.K., Tan B.H. (2006), Study of microstructure, phase and microhardness distribution of HVOF sprayed multi-modal structured and conventional WC–17Co coatings, Journal of Materials Processing Technology, Vol. 174, No.1-3, 305–311.
4. Żórawski W. (2013), The microstructure and tribological properties of liquid-fuel HVOF sprayed nanostructured WC–12Co coatings, Surface and Coatings Technology, Vol. 220, 276-281.
5. Sahraoui T., Guessasma S., Jeridane M. A., Hadji M. (2010), HVOF sprayed WC–Co coatings: Microstructure, mechanical properties and friction moment prediction, Materials and Design, Vol. 31, No.3, 1431 – 1437.
6. Saha G.C., Khan T.I., Zhang G.A. (2011), Erosion–corrosion resistance of microcrystalline and near-nanocrystalline WC–17Co high velocity oxy-fuel thermal spray coatings, Corrosion Science, Vol. 53, No.6, 2106–2114.
7. Wood R.J.K. (2010), Tribology of thermal sprayed WC–Co coatings, International Journal of Refractory Metals and Hard Materials, Vol. 28, No.1, 82–94.
8. Hulka I., Uţu D., Şerban V.A. (2011), Micro-scale sliding wear behavior of HVOF sprayed WC-Co(Cr), Annals of Faculty Engineering Hunedoara – International Journal of Engineering, Vol. 9, No.2, 61-64.
9. Hong S., Wu Y., Zheng Y., Wang B., Gao W., Lin J. (2013), Microstructure and electrochemical properties of nanostructured WC–10Co–4Cr coating prepared by HVOF spraying, Surface and Coatings Technology, Vol. 235, 582–588.
10. Santana Y.Y., La Barbera-Sosa J.G., Caro J., Puchi-Cabrera E.S., Staia M.H. (2008), Mechanical properties and microstructure of WC–10Co–4Cr and WC–12Co thermal spray coatings deposited by HVOF, Surface Engineering, Vol. 24, No.5, 374-382.
11. Berget J., Rogne T., Bardal E. (2007), Erosion–corrosion properties of different WC–Co–Cr coatings deposited by the HVOF process—influence of metallic matrix composition and spray powder size distribution, Surface and Coatings Technology, Vol. 201, No.18, 7619–7625.
12. Maiti A.K., Mukhopadhyay N., Raman R. (2007), Effect of adding WC powder to the feedstock of WC–Co–Cr based HVOF coating and its impact on erosion and abrasion resistance, Surface and Coatings Technology, Vol. 201, No.18, 7781–7788.
13. Zavareh M.A., Sarhan A.A.D.M., Razak B.B.A., Basirun W.J. (2015), The tribological and electrochemical behavior of HVOF-sprayed Cr3C2–NiCr ceramic coating on carbon steel, Ceramics International, Vol. 41, No.4, 5387–5396.
14. Kaur M., Singh H., Prakash S. (2009), High-Temperature Corrosion Studies of HVOF-Sprayed Cr3C2-NiCr Coating on SAE-347H Boiler Steel, Journal of Thermal Spray Technology, Vol. 18, No.4, 619-632.
15. Hong S., Wu Y., Wang Q., Ying G., Li G., Gao W., Wang B., Guo W. (2013), Microstructure and cavitation–silt erosion behavior of high-velocity oxygen–fuel (HVOF) sprayed Cr3C2–NiCr coating, Surface and Coatings Technology, Vol. 225, 85–91.
16. Brezinová J., Guzanová A., Egri M., Malejčík J. (2011), Evaluation of thermal sprayed coatings properties in terms of erosive wear, *Chemické listy: special issue*, Vol. 105, No. 17, 775-776.
17. Brezinová J., Guzanová A., Egri M. (2012), Change in properties of HVOF coatings under conditions of thermal cyclic loading, *Chemické listy*, Vol. 106, No. S3, 383-386.
18. Brezinová J., Guzanová A. (2012), Possibilities of utilization high velocity oxygen fuel (HVOF) coatings in conditions of thermal cyclic loading, *Metalurgija*, Vol. 51, No. 2, 211-215.
19. Brezinová J., Guzanová A., Draganovská D., Egri M. (2013), Assessment tribological properties of coatings applied by HVOF technology, *Acta Mechanica et Automatica*, Vol. 7, No. 3, 135-139.
20. Brezinová J., Guzanová A., Draganovská D. (2015), *Abrasive Blast Cleaning and Its Application*, 1st. Ed., Pfaffikon: Trans Tech Publications, 107 p.
21. Staia M.H., Ramos E., Carrasquero A., Roman A., Lesage J., Chicot D., Mesmacque G. (2000), Effect of substrate roughness induced by gritblasting upon adhesion of WC-17%Co thermal sprayed coatings, *Thin Solid Films*, Vol. 377-378, 657-664.

# DESTRUCTION OF SILICONE PROBES OF THE ATOMIC FORCE MICROSCOPE CAUSED BY THE ELECTROSTATIC BREAKDOWN DURING SCANNING OF DIELECTRIC SURFACES

Titarenko V. [1], Bilokin S. PhD. [1], Ass. prof. Bondarenko M. PhD. [1], Ass. prof. Bondarenko Yu. PhD. [1], Prof. Antonyuk V. Dr. Eng. [2]
Faculty of Electronically Technologies and Robotics – Cherkassy State Technological University, Ukraine [1]
Faculty of instrument-making – National Technical University of Ukraine "Igor Sikorsky Kyiv Polytechnic Institute", Ukraine [2]

maxxium23@gmail.com

***Abstract:*** *The results of microprocessing by the ribbon-shaped electron beam of the elements of optical measuring instruments (the material of such elements - K8 glass) with the initial nanorelief of surfaces 15-22 nm after industrial grinding and polishing are presented. Based on the results of studies using a computerized complex control system based on an atomic force microscope, it was established that after electron-beam microprocessing, the nanorelief of optical elements of measuring instruments decreased to 1.5-2.2 nm, satisfying to the requirements put forward to their surfaces.*

**Keywords**: ELECTRON-BEAM MICROPROCESSING, OPTICAL GLASS, COMPLEX CONTROL, COMPUTERIZED SYSTEM, ATOMIC-FORCE MICROSCOPY

## *1. Introduction*

For the manufacture of optical elements of measuring devices and the formation of their microprofile of the necessary size and shape on them, over the last decades all known materials of amorphous, crystalline, polycrystalline structure have been tested, and for their processing various methods were used, including: industrial deep grinding and polishing methods, grinding and polishing, and the etc.

As research has shown, modern ukrainian optical production is not guaranteed to receive surfaces on an optical glass that would satisfy the requirements imposed on such optical elements. Herewith, the nanorelief in industrially manufactured products exceeds the value of 5 nm, which limits their further use as precision optical elements of optical measuring systems.

At the same time, the impact on the surface of the optical material of abrasive, washing and pickling solutions in the grinding and polishing stages inevitably leads to the formation of chemically heterogeneous defect and fractured layers, the total depth of which can exceed tenths of micrometers. This, in many cases, limits the use of electronic lithography and photolithography technologies.

The problem of compliance with the necessary level of nanorelief of the surface layer of optical materials in the manufacture of elements of a new generation, increasing the productivity of their manufacture is one of the most relevant in the technology and technology of processing optical materials.

One of the ways to overcome this problem is to attract new tools for the energy microprocessing of optical surfaces, including concentrated electron fluxes.

The efficiency of processing optical glass by a ribbon-based electron beam was first shown in the works V.M. Lisochenka [1].

In papers [2, 3], is shown the possibility of flexible control of the process of electron-beam processing of optical glass and optical ceramics by melting the surface to a depth of up to 200 μm. The authors [4-6] confirmed the efficiency of the use of a ribbon-based electron beam for surface treatment of both optical and technical glass.

At the same time, the question of the qualitative changes in the nanorelief and the defective layer of the optical glass of the silicate group from the action of the low-energy electron beam ($E \leq 6$ keV) has not been studied sufficiently and the relationship between these changes and the parameters of electron-beam microprocessing.

The aim of this work is to determine the changes in nanorelief of the surface of elements from optical glass under the influence of a low-energy electron beam and to establish the relationship between the size of the modified nanorelief and the parameters of electron-beam microprocessing.

## 2. Experimental method

Objects that are treated with an electron beam: plane-parallel round plates (diameter 20 mm, thickness 2, 4, 6 mm) from glass of optical colorless grade K8 with silver metal coatings applied to their surface. Such objects are widely used in measuring devices as optoelectronic sensors (pressure, capacitance, density of medium, etc).

The study of processing objects was carried out using a computerized system of complex control, manufactured on the basis of an atomic force microscope (AFM) "NT-206" (the manufacturer of "Microtestmashines", Gomel, Belarus). For visualization of the object of investigation at a magnification of 100 times, used optical chamber "Logitech", whose viewing field is 1×0,75 mm$^2$.

The schemes for determining the surface nanorelief using a computerized integrated control system for non-contact (a) and contact (b) AFM schemes are shown in Fig.1.

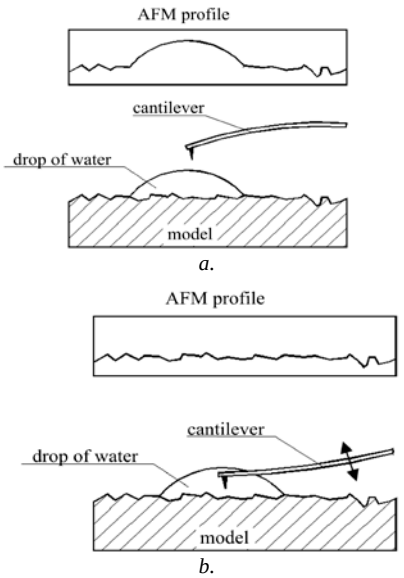



***Fig. 1.*** *Obtained surface profiles for noncontact (a) and contact (b) operation schemes of a computerized integrated control*

*system based on the atomic force microscopy method.*

The sensitive element of the microscope is the cantilever, the deflection of which, when in contact with the surface, is determined by means of a laser beam. The positioning of the surface to be measured under the cantilever is carried out by means of high-precision stepping motors (in the X-Y plane with a pitch of 2.5 μm, along the Z axis with a step of 200 nm).

The profile of the surface to be examined is determined by scanning the cantilever in the X-Y plane in a 13×13 μm section using a piezoceramic scanner in steps of up to 1 nm. The displacement of the cantilever along the vertical axis is carried out by a piezotube with a pitch of 0.02 nm in the range 3 μm. The image of the microrelief of the optical surface was obtained by applying the following operating modes of the AFM: static (contact), Fig. 1a, and dynamic (noncontact), Fig. 1b.

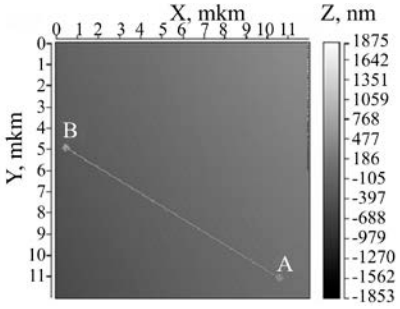
In dynamic mode, the cantilever is superimposed on the vertical axis with a frequency of 10 Hz to 400 kHz. The main advantages of this mode are the significantly increased sensitivity of the measuring system (it is theoretically possible to achieve an atomic resolution of the device) and to ensure the mechanical integrity of the probe and sample.

The positioning of the cantilever above the surface of the optical glass and the further settings of the "laser beam-cantilever" system occurs in manual mode using the long-focusing camera "Logitech" built into the AFM device with a 150-fold increase in the image on the PC display. As can be seen from Fig. 2, the correct positioning of the cantilever, which provides the most complete and accurate information retrieval by the sensitive AFM system on the topology of the surface, is achieved by focusing the laser of the photo detecting device on the upper edge of the cantilever.

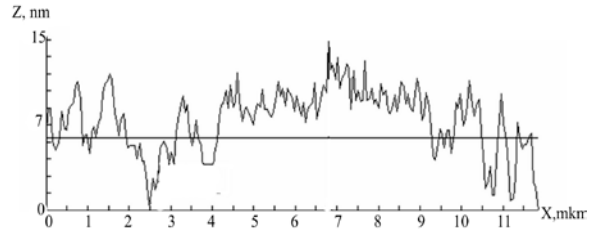
The scanning process is completed automatically, after which the computer monitor received a surface image. For processing and analysis of data from the microrelief, the programm Surface v.6.2 was used, which provides such types of information: three-dimensional visualization of the surface; surface profiling in the required section; distribution of surface heights; angular histogram.

The average time to prepare for work and scan one sample is 10...12 minutes.

The use of the atomic force microscopy method, it was possible to investigate the surface modified by the electron beam and the surface layer of the K8 glass product (Fig. 2).




*a.*




*b.*

***Fig. 2.*** *Appearance (a) and nanorelief along the AB (b) line of the surface area (12×12 μm) of the fragment of the plate of the optoelectronic capacitance sensor from K8 glass with a metallic thin silver film fused in its surface by an electron beam (film thickness 350 nm).*

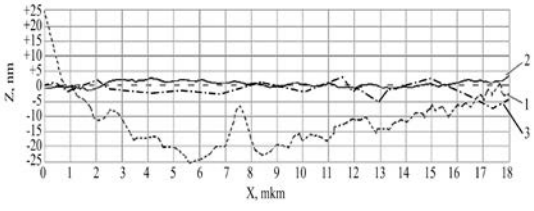
## *3. Results and discussion*

The results of the investigation and comparison of the nanorelief of the element surface from the optical glass K8 after machining, laser and electron beam microprocessing with applying a modern computerized complex control system for nanometric studies have shown the promise of this method in metrology, in integral optics at the manufacture and use as elements of measuring devices of micro- and nano-optical elements [7].

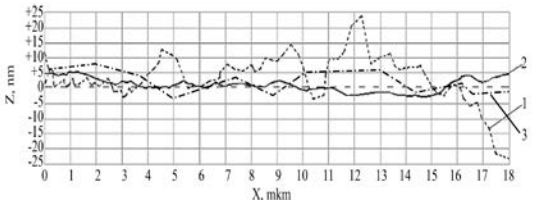
According to the profiles shown in Fig. 3, it can be concluded that both after mechanical (deep grinding-polishing) (profile 1, Fig. 3a) and after laser microprocessing (profile 3, Fig. 3b), the surface of the plate from optical glass has a characteristic nanorelief, which is much higher than the allowable value of the arithmetic average of the nanoscale, which is 5 nm.

This indicates the inability to use these methods of surface microprocessing in the manufacture of optical elements of measuring systems of modern instrumentation.

At the same time, the nanorelief of the surface obtained after electron-beam microprocessing (profile 2, Fig. 3a, b) indicates high accuracy and uniformity of the surface created, and the use of this method allows obtaining high-quality surfaces with guaranteed levels of purity and microroughness, whose value does not exceed 5 nm.




*a.*




*b.*

***Fig. 3.*** *The characteristic nanorelief of the surface of optical elements from K8 glass after mechanical (1), electron beam (2), and laser (3) processing (NT-206).*

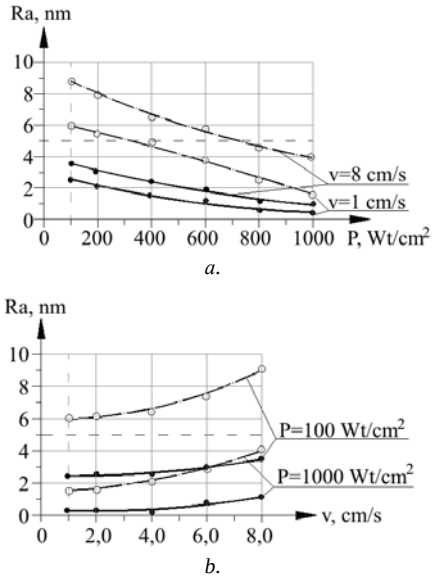



***Fig. 4.*** *Dependence of the average arithmetic roughness of the nanorelief Ra on the specific power of the electron beam P (a) and the speed of electron-beam micromachining v (б): ○ – by the works [8, 9]; ● – by the advanced technology; -- -- -- the maximum permissible values of the nanorelief on surfaces for optical elements*

Further studies of the nanorelief of the surface of elements (on the example of circular plates with a diameter of 20 mm and a thickness of 2 mm, optical glass K8) made it possible to establish the dependence of the arithmetic average roughness Ra on the specific power of the electron beam *P* (Fig. 3a) and on the speed of the electron beam *V* (Fig. 3b).

As can be seen from the dependences shown in Fig. 4a, b, according to the technological regimes described in Refs. [8 and 9], an increase in the specific power of the electron beam at 300 W/cm$^2$ for electron flow velocities of the order of 1 cm/s sec to 750 W/cm$^2$ for electron flow velocities of 8 cm/s leads to a decrease in the arithmetic average of the surface roughness below the permissible value of 5 nm. Herewith, according to the technological regimes obtained for improved technology for electron flow rates of 1-8 cm/s, the average arithmetic nanovelities for the entire range of specific power (100-1000 W/cm$^2$) is 2.2-1.5 nm.

## *4. Conclusion*

In the process of performing scientific research, changes in the nanorelief of the surface of optical elements from glass for measuring system devices from the action of low energy electron flux have been determined, and the relationship between the size of the modified nanorelief and the parameters of electron-beam microprocessing.

It is established that as a result of electron-beam microprocessing the nanorelief of the surfaces of products from optical glass K8 decreases from 4-9 nm to 1.5-2.2 nm. This is achieved by controlling the speed and power of the electron beam.

The obtained surfaces of optical elements made of K8 glass with a nanorelief of 1.5-2.2 nm satisfy the requirements imposed by modern production of metrological measuring means for such optical elements.

## *Literature*

1. Lisochenko V.N. Razrabotka elementov integralno-opticheskikh skhem novymi metodami na osnove elektronno-luchevoi obrabotki (*Development of elements of integrated-optical circuits by new methods based on electron-beam processing*) / V.N.Lisochenko, G.V.Kanashevich, V.A.Vashchenko i dr. – otchet po NIR Cherkasskogo filiala KPI. – Cherkassy. – 1993. – 205 s.

2. Kanashevich G.V. Tekhnologichni mozhlivost elektronno-promenevo obrobki optichnogo skla (*Technological possibilities of electron beam processing of optical glass*) / Visnik CHITI, 1998, No.3. – S. 48-55/

3. Kanashevich G.V., Kotel'nikov D.I., Vashchenko V.A. Special'ni metodi obrobki optichnogo skla (*Special methods of optical glass processing*) / Pid red. Profess. D.I. Kote-l'nikova. – CHernigiv: “Sivers'ka dumka”, 2002. – 215 s.

4. *Bondarenko M.* Peculiarities of metalized surfaces modification of silicon elements of microelectromechanical systems with low-power electronic flow / *M.Bondarenko, I.Bondarenko, V.Antoniuk* [etc.] // Materials science. Non-equilibrium phase transformations. – 2017. – Year III. – Issue 2. – pp.53-55.

5. *Kovalenko Y.I.* Study of ordered oxide patterns got on the dielectric surfaces with the combined electronic technology / *Y.I.Kovalenko, M.A.Bondarenko, E.V.Vertsanova, I.V.Iatsenko* [etc.] // Physics and technology of thin films and nanosystems: XIV Intern. conf.: thesis, May, 20-25, 2013. - Ivano-Frankivsk, 2013. – pp. 92.

6. Antonyuk V.S. Pidvishchennya mikrotverdosti ta znosostijkosti poverhon' elementiv virobiv z optichnogo skla mikroobrobkoyu elektronnim potokom u vakuumi (*Increase of microhardness and wear resistance of elements of products from optical glass by microprocessing by electronic flow in vacuum*) / V.S.Antonyuk, YU.I.Kovalenko, YU.YU.Bondarenko, M.O.Bondarenko // Visnik ZHitomirs'kogo derzhavnogo tekhnologichnogo universitetu. Seriya: Tekhnichni nauki. – ZHitomir: ZHDTU, 2015. – №1 (72) – S. 3-8.

7. Bondarenko M.O. Avtomatizovanij kompleks dlya nanometrichnih doslidzhen' (*Automated complex for nanometric research*) / M.O.Bondarenko, YU.YU.Bondarenko // Fizika, elektronika, elektrotekhnika (FEE-2016): nauk.-tekhn. konf., 18-22 kvitnya 2016 r: tezi dop. – Sumi: SumDU, 2016. – S. 200.

8. *Yatsenko I.* Influence of parameters by electronic ray on properties of superficial layers of optical elements of exact instrument-making / *I.Yatsenko, V.Antoniuk, M.Bondarenko, V.Vashchenko* // Innovations in ingeneering: Intern. scien.-tech. conf., 9-12 september 2015. – Burgas, Bulgaria. – Vol. 20/183. – 2015. – pp. 64-66.

9. Bondarenko M.O. Optimizaciya parametriv strichkovogo elektronnogo potoku za dopomogoyu zon termichnogo vplivu (*Optimization of the parameters of the tape electronic stream with the help of zones of thermal influence*) / M.O.Bondarenko, V.A.Vashchenko, G.V.Kanashevich // Tezi dopovidej pershoï Mizhnarodnoï NTK “Mashinobuduvannya ta metaloobrobka – 2003”. – Kirovograd, 17-19 kvitnya 2003. – S. 15-16.

# CHEMICAL NANOTECHNOLOGY OF MOLECULAR LAYERING AND INNOVATIVE SOLUTIONS BASED ON IT

ХИМИЧЕСКАЯ НАНОТЕХНОЛОГИЯ МОЛЕКУЛЯРНОГО НАСЛАИВАНИЯ И ИННОВАЦИОННЫЕ РЕШЕНИЯ НА ЕЕ ОСНОВЕ

Prof. dr. Malygin A.
Department of Chemical Nanotechnology and materials for electronics,
Saint-Petersburg State Technological Institute (Technical University), Russia, malygin@lti-gti.ru

**Abstract:** *The principles and peculiarities of the molecular layering (ML) method, known often in foreign works under the name of Atomic Layer Deposition, are considered. ML method was created in the middle of the last century by Soviet-Russian scientists V. B. Aleskovskii and his student S. I. Koltsov. Among the first who after Russian scientists began to carry out research on the method of ML were scientific groups from Finland (T. Suntola, S. Hauk, M. Leskela, M. Rital, etc.), the GDR (V. Hanke, G. Olman, B. Horvath and others), Bulgaria (G. Bliznakov, K. Petrov, D. Mekhanjiev, D. Damianov and others). The structural-dimensional effects manifested in products obtained using the ML method are analyzed. The results of practical application of nanotechnology on the principles of the ML method in various high-tech industries are presented: sensor sensors, membrane catalytic processes, catalysts, sorbents, composite materials, alternative energy sources, electret materials etc.*

**KEYWORDS**: SOLID, SURFACE, NANOTECHNOLOGY, STRUCTURAL DIMENSIONAL EFFECTS, FUNCTIONAL PROPERTIES, HIGH-TECH, MOLECULAR LAYERING

## *1. Introduction*

The method of molecular layering (ML), created more than half a century ago, seems to be very promising for the synthesis of materials of the "core—shell" type[1, 2]. The main idea of the ML method consists in the sequential build up of monolayers of structural units of a given chemical composition and structure on the surface of a solid phase matrix due to the realization of chemical reactions between functional groups (FGs) of a solid and the reagents supplied to them under conditions far from thermochemical equilibrium. The process is self organizing, since after the entry into the reaction of all available FGs, no more than one monomolecular layer is formed on the surface of the substrate. The process is most often carried out in the gas phase at atmospheric pressure in a carrier gas stream or in a vacuum.

The method of ML on the surface of solids, different in size, shape, structure, and composition, can be used to synthesize monolayers, including multicomponent ones, new functional groups, and to carry out atom by atom chemical assembly of surface nano-, micro- and macro- structures by repeatedly alternating chemical reactions according to a given program [2, 3].

In general, synthesis by the ML method can be represented by the equations (1, 2):

(1) $2MnB + AC_4 \rightarrow (Mn)_2AC_2 + 2BC$

(2) $(Mn)_2AC_2 + AB_4 \rightarrow (Mn)_2AAB_2 + 2BC$

It is possible to obtain a layer of A atoms whose thickness will be determined by the number of ML cycles by repeating the cycles of ML reactions (1) and (2) as many times as necessary:

(3) $(Mn)_2AAB_2 + AC_4 \rightarrow (Mn)_2AAAC_2 + 2BC$ etc.

It is possible to obtain multizone layers with a given mutual arrangement of layers of a given thickness, but differing in chemical composition, by using the reagents of different chemical nature (for example, NB4 ) at different stages of synthesis (4):

(4) $(Mn)_2AC_2 + NB_4 \rightarrow (Mn)_2ANB_2 + 2BC$

The transformation schemes shown in Fig. 1 illustrate the main synthetic routes of different coatings by the ML method. Thus, it is possible using the ML method to design the surface of solids at the atomic-molecular level, creating the structures of any given composition and the structure chemically bound to the matrix.

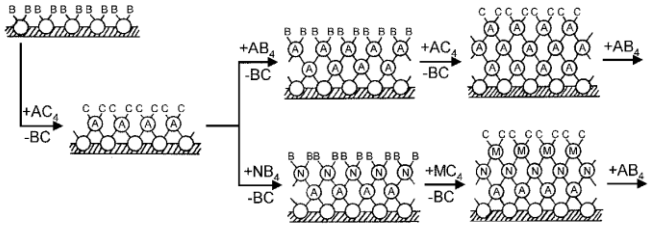



*Fig. 1. Chemical constructing of nanostructures on the surface of solids by the Molecular layering method*

The aim of this article is to present some results of research in Russia in the field of the creation by ML method of materials with various functional properties.

## *2. Results and discussion*

Theoretical and experimental studies of products obtained by the ML method allowed us to reveal fundamental structural and dimensional effects associated with the synthetic capabilities of this precise synthesis and affecting the functional properties of materials:

- the monolayer effect — drastic changes in properties of the material after one - four ML cycles;
- the substrate shielding effect is physical overlapping of the surface after four - six ML cycles;
- the effect of a multicomponent system is regular or non additive (synergistic effect) change of properties of material at a given ratio and mutual arrangement of mono and nanolayers;
- the mutual structural coordination effect of surface of substrate and growing layer — influence on the conditions of phase formation and solid state reactions in the system.

Following main routes for the application of the ML method can be distinguished after the analysis of possible areas of application for new precision technology and taking into account the observed regularities and various directions in the development of chemical material science using "core—shell" systems:

— synthesis of extremely thin coatings with a thickness from one to several monolayers, when it is necessary to obtain and evenly distribute very small amounts of substance on the surface of a solid phase matrix in such a way that each attached atom or group of atoms is available for further physicochemical transformations;

— creation of relatively thick coatings, up to several tens and hundreds of nanometers thick, formed with an accuracy of up to one monolayer, which is important for optimizing the composition, thickness, and structure of the layer, and, consequently, the functional characteristics of the material;

— formation of multicomponent mono- and nano-layers, when it is necessary to create polyfunctional coatings or synergistic systems;

— regulation of interactions between the surface centers of a solid and the reagents supplied to them in obtaining a coating with the specified composition and structure, which is of interest for the subsequent optimization of the regimes of secondary physicochemical and thermal transformations of the "core — shell" type composition.

*The monolayer effect* (ME), consisting in a sharp change in the properties of the matrix after the deposition of from one to four monolayers of new structural units, has found application for objects where it is required to distribute evenly and attach firmly small quantities of the substance on a sufficiently developed surface, including a porous space (with a specific surface area from units to hundreds and thousands of square meters per 1 g). This concerns layers from partial monolayer to several monolayers of doping additives for different purposes (activating or inhibiting physicochemical transformations of the matrix, protective, strengthening, etc.). [2 – 6].

Such materials include, first of all, catalysts, sorbents, highly disperse fillers of composite materials, pigments, etc.

The reaction of $VOCl_3$ with surface hydroxyl groups of silica gel results in the formation of monolayer of groups with main formula $(\equiv Si\text{-}O\text{-})_3VO$ on pore support. It was used to obtain the indicator for water vapours. The color of vanadium-containing silica gel (IVS-1) is essentially dependent on the humidity of air flow (Table 1).

***Table 1.*** *Indicator characteristics of vanadium containing silica gel (IVS-1)*

| Relative humidity given at 20°C, % | Response time (no more than), min | Coloring of face layer of IVS-1 |
|---|---|---|
| 0.05 | 20 | Pale yellow tone |
| 0.5 | 20 | Lemon |
| 1.6-4.5 | 15 | Yellow |
| 6-10 | 15 | Bright - orange |
| 10-13 | 15 | Dark - orange |
| 15-45 | 15 | Red, dark - red |
| 48-60 | 25 | Brown |
| 70-95 | 25 | Black-brown |

It is a reversible sorbent - indicator for water vapors, and it is regenerated at 200-400°C. It is important to note, that the sample with two or more V-O monolayers on silica loses of indicator properties.

It is known that phosphorus (+5) oxide actively reacts with vapors of water. And it can be used for drying of gases. But it is rather bad that the phosphoric acid is formed and it regeneration is difficult. It was created a sorbent on a basis of silica with P-oxide nanolayer (PhS-1-3). It is an active sorbent of vapors of water and it is better in 5-6 times, than initial silica (Table 2).

***Table 2.*** *Moisture capacity of initial and of phosphorus - containing silica gel (at humidity about 70 %)*

| Sample | The content of P, mmol/g | Adsorption capacity, % | Remark |
|---|---|---|---|
| 1 | 2 | 3 | 5 |
| Initial silica gel ShSK | 0 | 6 | - |
| ShSK impregnated by $H_3PO_4$ | 4,06 - 1,02 | 20 | The sample is covered with a sticky film |
| PhS 1 | 1,0 | 20 | |
| PhS 2 | 1,3 | 25 | — |
| PhS 3 | 1,6 | 35 | |

PhS-1-3 also adsorbs of ammonia, of organic vapor. New sorbents are used in the industry for clearing and stabilization of the gas atmosphere in devices.

The other example - doped ceramics for ceramic insulators in the technology of X-ray tubes [2, 7].

Several years ago industrial company "Svetlana-Roentgen" addressed us to do research to reduce the sintering temperature of ceramic mass by at least 100 degrees. We synthesized titanium-oxide layers on the surface of particles by the ML method.

Characteristics of sintering of the initial and modified ceramic mass by ML and mechanical mixing methods are presented in Table 3.

***Table 3.*** *Characteristics of sintering of the initial and modified ceramic mass by using of ML method (nTi - after 1 – 4 cycles ML) in compare with mechanical mixing*

| Sample | $TiO_2$ % by weight | $T_{initial}$ °C | - ΔT °C | Shrinkage % |
|---|---|---|---|---|
| Initial | 0,06 | 874 | 0 | 0.50 |
| Initial +$TiO_2$ | 0,21 | 864 | -10 | 0.66 |
| 1 Ti | 0.26 | 780 | -94 | 0.99 |
| 2 Ti | 0.42 | 740 | -134 | 1.11 |
| 3 Ti | 0.57 | 740 | -134 | 1.20 |
| 4 Ti | 0.70 | 740 | -134 | 1.20 |

As can be seen from the data in the Table 3, after 2-4 ML cycles, the sintering start temperature is reduced by 134 degrees.

This material is used for the manufacture of ceramic insulators in the production of X-ray tubes.

Rather interesting direction of ME application in the creation of electret polymer materials has been formed in recent years[8 - 10]. It is known, that upon irradiation of polymer dielectrics with a flux of charged particles (ions, electrons), a charge is accumulated on their surface, i.e. an electret state occurs. The charged state of such materials, which are called electrets, can persist for a fairly long time (up to several years).

Electrets are used in modern hightech products, in particular, in creating electroacoustic transducers, sensors, and also nonlinear optical elements [11, 12]. An important factor for the practical application of these systems is the stability of their electret state.

Very interesting perspective results on the use of monolayer effect when creating electret materials.

Polytetrafluoroethylene (PTFE) films were modified using ML method by treatment with titanium tetrachloride and water vapor.

Film samples were pretreatment in a positive corona discharge. The charge stability on the surface of polymer was then investigated at different temperatures. It was found that the decrease of surface potential in modified films begins at higher temperatures (fig. 2).

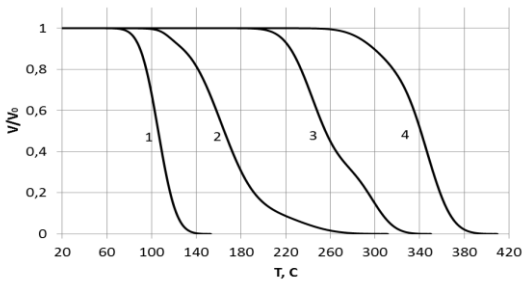



***Fig. 2.*** *The charge stability of thermally stimulated surface of PTFE nanocomposite:1 – original, 2 - plasma treated, 3 – modified by $TiCl_4$ and $H_2O$, 4 – plasma treated and modified by $TiCl_4$ and $H_2O$*

The first results on the creation of electret materials with the use of ML were further developed using other polymers and modifiers

*The substrate shielding effect (SSE)* is manifested after the formation of a nanolayer with the thickness of more than four or six

monolayers, physically screening the sur face from external influence. The thickness of such a coating was calculated theoretically [13].

One of the promising areas is the use of SSE in a creation of shell pigments and fillers. Using a particle of cheap material (for example, waste products in metallurgy and mining) as a "core", the ML method can be used to form a "shell" of the optically active product on their surface (titania, zinc oxide nanolayers in the production of white pigments, chromium oxide, iron oxide nanolayers for the creating of color pigments). A complex of such studies was carried out at the end of the last century [14 – 17].

Today is a very dynamically developing direction for the creation of sensors. One of the most promising is a fiber-optic sensors (FOS). One important characteristic is the magnitude of the reflected light output from the end face of the optical fiber (fig 3).

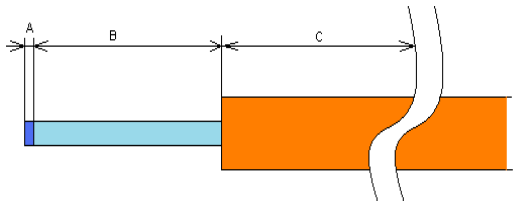



***Fig. 3*** *Diagram of the FOS element*

A – functional nano-coating; B – quartz optical fiber; C - optical fiber with a polymer coating)

It was shown, that with increase of number of ML cycles also increase reflected light power (fig 4).

To further increase the value of the reflected power is necessary to create on the surface of a two-component nano-coating with thickness corresponding to the first maximum in the sine wave.

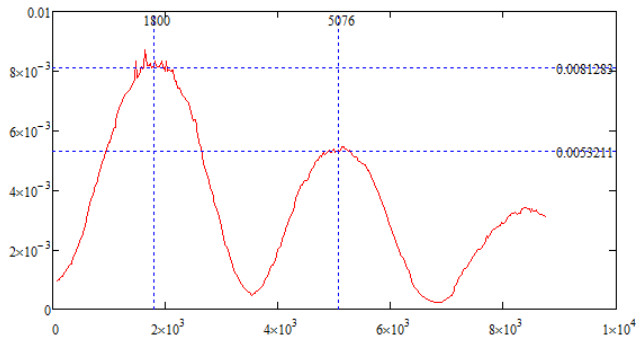



***Fig. 4*** *The magnitude of the reflected light power depending on the number of cycles ML (Laser with a wavelength of 1310 nm)*

Fig. 5 shows AFM data for zirconium-oxide coating on the lateral surface of fiber that provides increased strength of fiber, as well as resistance to high temperatures.

Interestingly, there are defects on the original surface of the fiber (fig 5, upper image), but after deposition of coating, these defects are no longer visible (fig 5, bottom drawing).

*The mutual structural coordination effect (MSCE)* is due to the chemical interaction of the atoms of applied low molecular weight reagents and the atoms of the original matrix.

As it was noted, the MSCE can significantly influence phase transformations of both the matrix and the growing layer, increasing the rate of solid phase reactions in the system. The results of a comparative study of phase transformations in a nanocomposite and in a mechanical mixture of a similar composition are presented in [18 – 21]. For example, it has been shown that the formation of mullite in a nanostructured composition takes place in just a few minutes (Fig. 6). The degree of conversion reaches only 0.4 at a much longer time in products of a similar composition obtained by mechanical mixing of silica and aluminum oxide.

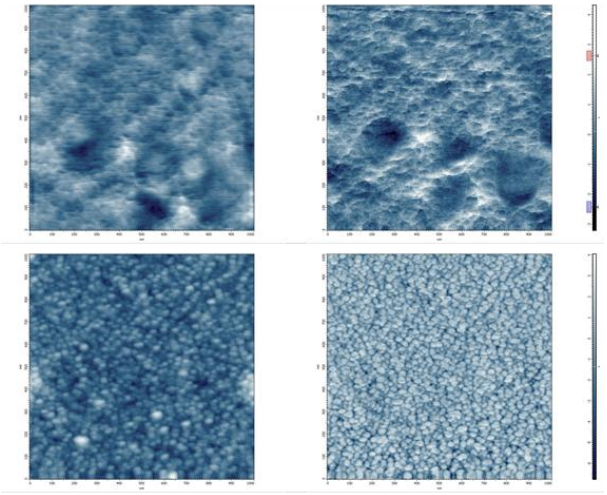


***Fig. 5.*** *AFM image of a side surface of the sapphire fiber: the initial (upper image) and the modified (bottom drawing) by Zr- oxide layer (400 ML cycles) (scanned area size 1 × 1 microns) (left - topography mode, right – mode of phase contrast)*

The results obtained make it possible to predict with sufficient confidence the application of the ML method and the mutual structural coordination effect of the synthesized layer and matrix in the processes of compaction of highly dispersed products widely used in the technology of binders, ceramic materials and products [20, 22, 23].

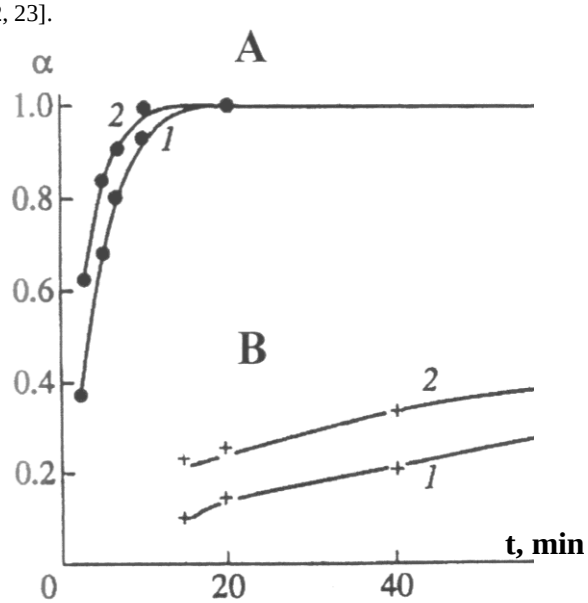



***Fig. 6*** *Transformation (α ) of $SiO_2$ and $Al_2O_3$ nanolayers into mullite: A- in nanosized structure of $Al_2O_3$ /nanolayer (4 Nm of $SiO_2$); B – in mixture of $SiO_2$ and $Al_2O_3$*

*The effect of a multicomponent system (MS)* is regular or non additive (synergistic effect) change of properties of catalists, sorbents, fillers of composite materials etc.

Multicomponent systems created by layer-by-layersynthesis have found application in the production of membrane catalysts. First, an oxide layer of one chemical nature with a certain thickness was created. This regulated the membrane pore structure. Then a catalytically active additive was applied to its surface [24 – 28] (fig 7).

The ML method was applied successfully to obtain nanostructured composite membrane catalysts by depositing metal oxide structures on the surface of a porous carrier. Low dimensional chromium—phosphorus oxides and other structures were used as the catalytically active compound.

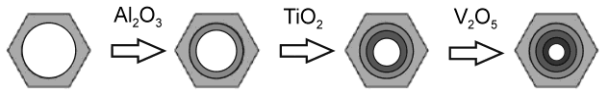



***Fig. 7*** *Change in pore diameter and application of the catalytically active component in the sequential treatment of the membrane with various reagents*

To prepare a membrane catalyst for the oxidative dehydrogenation of methanol to formaldehyde, vanadium and vanadium—phosphorus oxides were synthesized in the pores of an asymmetric tubular membrane of $\alpha Al_2O_3$ with a thin layer of narrow porous $\gamma Al_2O_3$. The synthesis was carried out by the ML method directly in the membrane reactor by alternative treatment of the carrier surface with $VOCl_3$—$H_2O$ or $PCl_3$—$H_2O$.

The results described in the publications [29, 30] have showed for the first time that the ML method is a simple and flexible way of modification of a porous inert membrane carrier, ensuring the application of the active component not only to the surface, but also to micro- and nanopores.

Thus, the presented results allow to draw a conclusion that using the ML nanotechnology, it is possible to assemble nanostructures of various functional purposes on the surface of porous carriers in a single chemical technological cycle. These nanostructures regulate the pore size of the carrier and impart the required catalytic properties to the system. The synthetic program includes as the main parameters the selection of the necessary reagents and the sequence of their feed to the reaction chamber.

Previously was investigated the catalytic properties of the $VOx/TiOy/\gamma\text{-}Al_2O_3$ systems (obtained by ML with using vapors of TiCl4 и VOCl3) in the reactions of oxidative dehydrogenation of methanol to formaldehyde, and ethane to ethylene. At the present time there were obtained and investigated multicomponent systems, such as $Mo(Nb)Ox/TiOy/\gamma\text{-}Al_2O_3$; $VOx/Mo(Nb)Oy/SiO_2$; $NbOx/VOy/SiO_2$ and others.

### *3. Conclusion*

Thus, the analysis of the results presented in this report allows us to conclude that to date a sufficiently reliable theoretical, experimental, and applied physicochemical basis has been created. It is really possible using this basis to set specific targets for the widespread introduction of nanotechnology in the industry for the production of solid phase materials and products for various func tional purposes. Based on the principles of the molecular layering method, taking into account the structural and dimensional effects in ML products, it is possible to adopt and implement innovative solutions in the most diverse directions of solid-phase materials science, to create new materials with various functional properties.

The work has financial support from the Russian Ministry for Education and Science (Project № 16.1798.2017/4.6).

### *4. References*

1. V. B. Aleskovskii, S. I. Kol´tsov, Tezisy dokladov nauchno tekhnicheskoi konferentsii Leningradskogo Tekhnolog. Insti tuta im. Lensoveta (Leningrad, 1965) [In Mater. Scientific Technical Conference of LTI by Lensovet], LTI by Lensovet, Leningrad, 1965, p. 67 (in Russian).
2. A. A. Malygin, V. E. Drozd, A. A. Malkov, V. M. Smirnov, CVD, 2015, 21, 216.
3. V. B. Aleskovskii, Stekhiometriya i sintez tverdykh soedinenii [Stoichiometry and Synthesis of Solid Compounds], Nauka, Leningrad, 1976, 140 pp. (in Russian).
4. S. I. Kol´tsov, V. M. Smirnov, V. B. Aleskovskii, Kinet. Catal., 1970, 11, 835.
5. A. A. Malkov, V. D. Ivin, in Termicheskii analiz i fazovye ravnovesiya [Thermal Analysis and Phase Equilibriums], Perm University, Perm, 1989, p. 32 (in Russian).
6. A. A. Malygin, in Nanomateriali: svoistva i perspektivnye prilozheniya [Nanomaterials: Properties and Promising Ap plications], Ed. A. B. Yaroslavtsev, Nauchnyi Mir, Moscow, 2015, p. 84 (in Russian).
7. A. A. Malygin, Russ. J. Appl. Chem., 1996, 69, 1419.
8. N. Yu. Efimov, A. A. Malygin, A. A. Rychkov, Russ. J. Appl. Chem., 2016, 89, 930.
9. D. Rychkov, A. Rychkov, N. Efimov, A. Malygin, R. Ger hard, Appl. Phys. A, 2013, 112, 283.
10. A. A. Rychkov, A. A. Malygin, S. A. Trifonov, D. A. Rych kov, Russ. J. Appl. Chem., 2004, 77, 276.
11. G. M. Sessler, in Electrets, Ed. G. M. Sessler, Springer Verlag, Berlin, 1980, p. 13.
12. Electrets, Ed. R. Gerhard, Multhaupt Laplacian Press, California, 1999, 338 pp.
13. S. I. Kol´tsov, J. Appl. Chem. USSR, 1970, 43, 1976.
14. A. M. Postnova, N. A. Stepanova, A. A. Malygin, Izv. Vuz., Khim. Khim. Tekhnol., 1988, 31, No. 10, 95.
15. Pat. USSR 1511261; Byul. Izobret. [Invention Bull.], 1989, 36.
16. Pat. USSR 1511262; Byul. Izobret. [Invention Bull.], 1989, 36.
17. Pat. USSR 1632965; Byul. Izobret. [Invention Bull.], 1990, 9.
18. V. V. Gusarov, A. A. Malkov, A. A. Malygin, S. A. Suvo rov, Russ. J. Gen. Chem., 1994, 64, 554.
19. V. V. Gusarov, A. A. Malkov, A. A. Malygin, S. A. Suvo rov, Inorg. Mater., 1995, 31, 320.
20. Zh. N. Smirnova, V. V. Gusarov, A. A. Malkov, T. V. Fir sanova, A. A. Malygin, S. A. Suvorov, Russ. J. Gen. Chem., 1995, 65, 168.
21. V. V. Gusarov, Zh. N. Ishutina, A. A. Malkov, A. A. Maly gin, Dokl. Chem., 1997, 357, 203.
22. Pat USSR 1710531; Byul. Izobret. [Invention Bull.], 1992, 5.
23. V. V. Gusarov, A. A. Malkov, A. A. Malygin, S. A. Suvo rov, Russ. J. Appl. Chem., 1994, 67, 834.
24. A. A. Malygin, A. A. Malkov, S. V. Mikhailovskii, N. L. Basov, M. M. Ermilova, N. V. Orekhova, G. F. Teresh chenko, Ross. nanotekhnologii [Nanotechnologies in Russia], 2010, 5, 153 (in Russian).
25. A. A. Malygin, A. A. Malkov, S. V. Mikhaylovskii, S. D. Dubrovensky, N. L. Basov, M. M. Ermilova, N. V. Ore khova, G. F. Tereschenko, in Membranes for Membrane Reactors: Preparation, Optimization and Selection, Eds A. Basile, F. Gallucci, Wiley, 2011, p. 357.
26. A. A. Malygin, M. M. Ermilova, V. M. Gryaznov, N. V. Orekhova, A. A. Malkov, Desalination, 2002, 144, 433.
27. G. F. Tereshchenko, N. V. Orekhova, M. M. Ermilova, A. A. Malygin, A. I. Orlova, Catal. Today, 2006, 118, 85.
28. M. M. Ermilova, N. V. Orekhova, G. F. Tereshchenko, A. A. Malygin, A. A. Malkov, A. Basile, F. Gallucci, J. Membrane Sci., 2008, 317, 88.
29. M. M. Ermilova, N. V. Orekhova, G. F. Tereshchenko,A.A. Malygin, A. A. Malkov, A. Basile, F. Gallucci,G. de Luca, Desalination, 2006, 200, 692.
30. V. M. Gryaznov, M. M. Ermilova, N. V. Orekhova, G. F. Tereschenko, in Structured Catalysts and Reactors, 2nd ed., Eds A. Cybulski, J. A. Moulijn, Taylor&Francis, London, 2005, p. 579.

# IMPROVING THE ECOLOGICAL INDICATORS OF GAS-FIRED BOILER PLANTS AT THE USE OF COMPLEX HEAT-RECOVERY SYSTEMS

Doctor of Technical Sciences, Professor, Corresponding Member of NAS of Ukraine, Honored Worker of Science and Technology of Ukraine Fialko N., Candidate of Technical Sciences (Ph. D.), Senior Scientific Researcher Presich G., Candidate of Technical Sciences (Ph. D.), Senior Scientific Researcher Navrodska R., Candidate of Technical Sciences (Ph. D.) Gnedash G., Candidate of Technical Sciences (Ph. D.) Shevchuk S.
Institute of Engineering Thermophysics of National Academy of Sciences of Ukraine, *Kyiv, Ukraine*
nmfialko@ukr.net

***Abstract:*** *To improve the operational and environmental performance of steam and water-heating gas-fired boilers, is proposed the efficient technology based on an complex heat-recovery system with heating and humidifying the blown air and heating the cold water of the chemical water-purification system. The results of studies on the reduction of harmful emissions into the environment by gas-fired boilers equipped by deep recovery systems of heat of the exhaust-gases are presented. The efficiency of use for reducing the fuel consumption and the level of formation of nitrogen oxides in the boiler furnace of such complex heat-recovery systems is considered. It is shown that the use of these systems secures reducing nitrogen oxide emissions by up to 60% by suppressing their formation in the boiler furnace at the introduction of moisture with blown air and decrease by 8-12% other harmful emissions from fuel combustion due to a reduction in its consumption.*

***Keywords****: EXHAUST-GASES; BLOWN AIR; NITROGEN OXIDES; CHEMICAL WATER-PURIFICATION SYSTEM*

## *1. Introduction*

Problems of environmental protection and energy-saving became priority in world practice. The main directions of deciding these pressing problems in municipal heat-power engineering is to improve the environmental indicators of heating boiler plants and increase the efficiency of using fuel in them through the use of technologies for deep recovery of the exhaust-gases heat [1-6]. The relevance of scientific problems in these directions is increasing due to the steady increase in the fuel-energy costs and the amplification of requirements to reducing environmental pollution.

## *2. Prerequisites and means for solving the problem*

To improve the environmental indicators of boilers, the efficient method is to reduce emissions of nitrogen oxides into the environment due to the suppression of their formation in the boiler furnace by the decrease in the combustion temperature. Reduction of this temperature can be achieved, in particular, by injection moisture into the combustion zone [5, 6]. Increase of thermal efficiency of boiler plants is realized at application of modern heat recovery technologies with deep cooling of exhaust-gases [4, 7-9].

In these technologies, the condensation mode of the heat-recovery equipment is realized, when, in addition to the so-called apparent heat of these gases, the latent heat of condensation of the water vapor contained therein. The implementation of the condensation mode also improves the environmental performance of the boiler by reducing fuel consumption and dissolving in the resulting condensate a part of the harmful emissions generated by its combustion.

In traditional heat-recovery systems, which are used primarily for heating boilers and intended only for heating the return heat-network water entering the boiler, this condensation regime is usually realized only in the autumn-spring time of the heating season under relatively low boiler load. In order to ensure this regime throughout the entire heating period, it is necessary to use the recovered heat also for heating the heat-transfer agents more coldest than the return heat-network water. Such heat-transfer agents can be blown air, cold water of the chemical water-purification system of the boiler plant, water for technological needs and other heat-transfer agents [1-3].

## *3. Solution of the examined problem*

This work is devoted to research on the efficiency of using complex heat-recovery systems for gas-fired boilers intended for heating and humidifying blown air and heating cold water for chemical water-purification system. In these systems, the heating the blown air and the water of the chemical water-purification system is served to increase the efficiency of fuel use in the boiler, and its humidification - to reduce the level of formation of nitrogen oxides due to a decrease in the combustion temperature in its boiler furnace.

The aim of the investigation is to estimate the levels of reduction of harmful emissions into the environment by hot-water and steam boilers in different modes of their operation when using heat-recovery technologies with humidification of the blown air entering the combustion zone.

The schematic circuit of a complex heat-recovery system with heating and humidifying the blown air and heating the cold water of the chemical water-purification system is shown in Fig. 1.

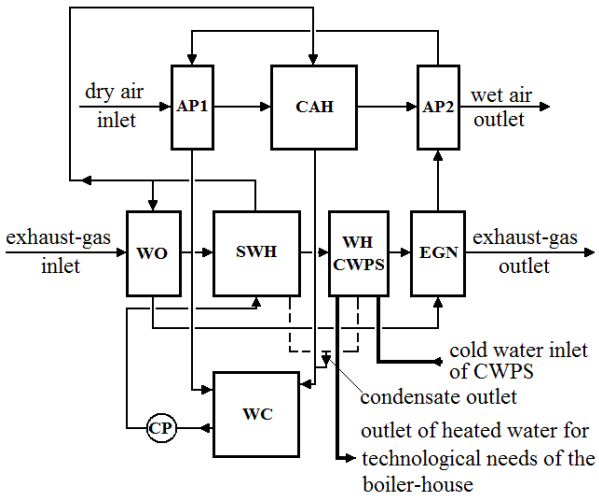



***Fig. 1*** *Schematic circuit of a complex heat-recovery system with heating and humidifying the blown air and heating the cold water of the chemical water-purification system: AP1 – first air preheater; CAH – contact air heater; AP2 – second air preheater; WO – water-overheater; SWH – surface water heater; WH CWPS – water heater of chemical water-purification system; EGH – exhaust-gas heater; WC – water collector; CP – the centrifugal pump.*

In this system, by using the heat of the exhaust-gases in the surface water heater SWH, the water of the circulation circuit is heated, part of which is directed to the contact air heater CAH. In the heater CAH through the contact of blown air with heated water in a layer of a filling of a certain type, occur heating and humidifying the air entering to the combustion in the boiler furnace. After the heat-exchanger SWH, the exhaust-gases are aftercooled in

the water heater WH CWPS of this complex system. When the gases are cooled in the heat-exchangers SWH and WH CWPS, a part of the moisture content of exhaust-gases condenses. The water collector WC is used to collected condensed formed in the SWH and WH CWPS and chilled water from the contact heater CAH. Before entering the chimney pipe, the cooled gases are dried in the exhaust-gas heater EGH to a level that prevents the condensate formation in this pipe. Water-overheater WO is designed to increase the thermal potential of water, the use of which is realized in the exhaust-gas heater EGH. Heat-exchangersAP1 and AP2 serve to preheat the blown air before it enters the contact air heater CAH and to heat the humidified air to prevent condensation in the chimney ducts. Heated and humidified air is direct to the boiler furnace. An increase in air temperature ensures a corresponding reduction in fuel consumption, and humidification of this air helps to reduce the formation of nitrogen oxides due to a decrease in the combustion temperature by using a portion of the thermal potential of the flame to heat the introduced moisture.

When carrying out investigations of the thermal and environmental indicators of this system, the load of the water-heating boiler was accepted in accordance with the temperature chart of the boiler with the temperature difference of the heat-transfer agent of 95-70° C, and the steam one - corresponded to two modes of its operation according to the order, namely: 100% and 50%. The environment temperature $t_{env}$ changed during the operation of boilers during the heating season from minus 20 to plus 10°C.

Determination of the thermal characteristics of the complex heat-recovery system under investigation was carried out according to known methods [10] using the calculated experimental dependences for the operation of equipment in the condensation modes obtained at the Institute of Engineering Thermophysics of National Academy of Sciences of Ukraine [11].

The volumes of $NO_x$ reduction were dependent on the water-fuel ratio β in the boiler furnace according to the data of [12]. Namely, the relative decrease in nitrogen oxides in combustion products due to the humidification of the blown air was calculated by formulas:

$$\mathbf{NO_x^{out} / NO_x^{in}} = 0{,}947 \cdot e^{-0{,}995\beta} + 0{,}066 \quad (1)$$

$$\beta = G_w/G_{ng},\ \text{кг/кг} \quad (2)$$

where β is water-fuel ratio; $G_{ng}$,$G_w$ – mass flows of natural gas and moisture introduced into the boiler furnace with blowing air.

## *4. Results and discussion*

Calculated data on the thermal efficiency of the use of the complex heat-recovery system under consideration for the two types of boilers are shown in Fig. 2.

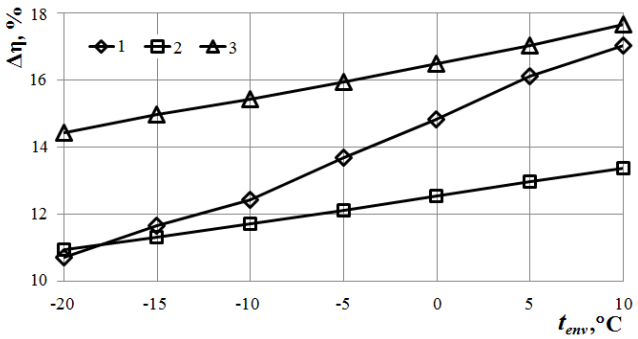



***Fig. 2*** *Dependence on the environment temperature the increase of the coefficient the use heat of fuel of boiler Δη of complex heat-recovery system with heating and humidifying the blown air and heating the cold water of the chemical water-purification system for hot-water and steam boilers:1 – water boiler; 2 – steam boiler with a power of 100%; 3 – steam boiler of 50% capacity.*

As can be seen from the presented results, the use of the proposed complex heat-recovery system provides for the boilers in question a significant increase in the coefficient the use heat of fuel, and, consequently, a decrease consumption of natural gas. Specifically: the value of the increase in the coefficient the use heat of fuel of boiler, depending on the operating mode, is 10.8 ÷ 16.6 % for the water-heating boiler, and for the steam boiler it is 11.1 ÷ 17.5 %. Reduction of fuel consumption ensures a corresponding reduction in emissions of harmful substances into the environment during the operation of these boilers.

The results of the investigation carried out to reduce the levels of formation of nitrogen oxides are shown in Fig. 3.

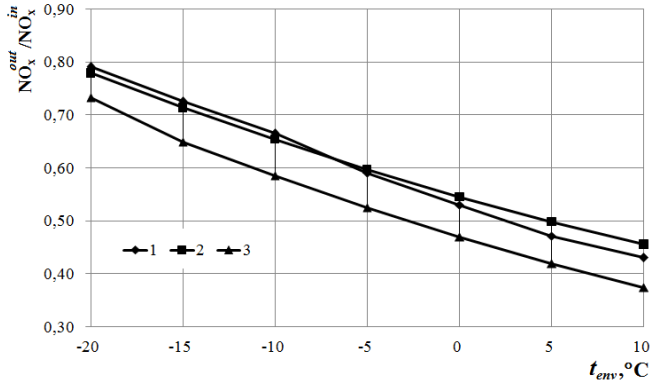



***Fig. 3*** *Dependence on the environment temperature the relative decrease of nitrogen oxides in the boiler furnace of the water and steam boilers in different modes of their operation with the use of a complex heat-recovery system under consideration: 1 – water boiler; 2, 3 – steam boiler with a capacity of 100 and 50%, respectively.*

The obtained data show that for the water-heating boiler, when using the proposed heat-recovery system, there is a relative decrease in $NO_x^{out}$ /$NO_x^{in}$ volumes of nitrogen oxides formation, from 22 % to 63%, depending on the operating mode of the boiler in accordance with the environment temperature $t_{env}$. The minimum value area $NO_x^{out}$ /$NO_x^{in}$ corresponds to the warm period of the heating season. This is due to the higher air temperature at the entrance to the system, and therefore into the contact heat exchanger CAH, and the decrease in its consumption in accordance with the operating mode of the boiler. This makes it possible to moisten the blown air to a higher level, and, accordingly, to increase the water-fuel ratio. This circumstance ensures a reduction in the volumes of nitrogen oxides formation in the boiler furnace.

For a steam boiler, the obtained data show that the range of variation of $NO_x^{out}$ /$NO_x^{in}$ also depends on the its operating mode and the inlet temperature of the heated air. The more significant reduction in the $NO_x^{out}$ /$NO_x^{in}$ ratio corresponds to 50 % of the boiler power. This is explained by a decrease in the consumption of blown air. So at the given load, the relative levels of reduction in the formation of nitrogen oxides vary from 27 % to 63 %, and at a load of 100 % – only from 21 % to 54 %. In this case, the larger values of this decrease correspond to elevated temperatures $t_{env}$, which is caused, as noted, to higher levels of air humidification, and hence also to the water-fuel ratio.

The work also assesses the reliability of the results obtained when estimating the level of nitrogen oxides emission reduction due to the introduction of moisture with blowing air into the boiler furnace by comparing the calculation data and experiments. The corresponding results are shown in Fig. 4.

The calculated values of the relative decrease in $NO_x$ (curve 5) were determined from formula (1). The experimental points corresponded to the results of other investigators [6] and personal measurements of $NO_x$ at the outlet from the complex heat-recovery system for heating and humidifying the blown air that is installed in the boiler-house of PSC “KYIVENERGO” (Kyiv, Ukraine).

Comparison of these results shows a satisfactory coincidence between the calculated and experimental data.

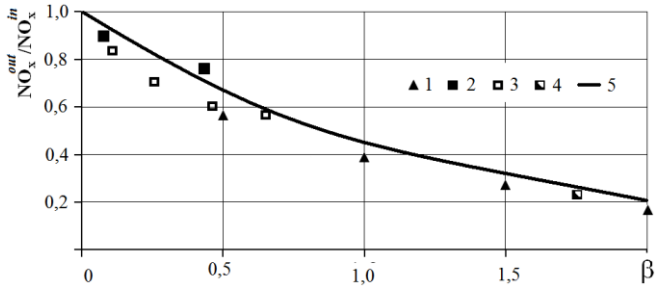



***Fig. 4*** *Comparative of calculated and experimental data of the relative NOx concentration in the exhaust-gases from the boiler with air humidification in the contact air heater of the complex heat-recovery system, depending on the water-fuel ratio β: 1, 2, 3 – experimental data of other researchers [12]; 4 – experimental data of personal tests; 5 – theoretical curve.*

## *5. Conclusion*

Application for gas-fired boilers modern technology with complex using recovery heat to heat the boiler water, water of chemical water-purification system and combustion air reduces the nitrogen oxide emissions to 60% by suppress their formation in the combustion chamber of the boiler. The use of this technology also ensures the reduction in fuel consumption in boilers by 10.8% ÷ 17.5 % and the corresponding reduction in other harmful emissions from combustion of fuel.

## *6. References*


1. Navrodskaya R. Energy-efficient heat recovery system for heating the backward heating system water and blast air of municipal boilers - Industrial Heat Engineering, V. 39, 2017, № 4, P. 69-75. (Navrodskaya, R., N. Fialko, G. Gnedash, G. Sbrodova).
2. Dolinskiy A. Basic principles of heat recovery technologies for boilers of the low thermal power - Industrial Heat Engineering, V. 36, 2014, № 4, P. 27-35 (Dolinskiy, A., N. Fialko, R. Navrodskaya, G. Gnedash).
3. Fialko N. Efficiency increase of municipal power boiler-installations system by the combined use of exhaust gases for heating - Alternative Energy and Ecology (ISJAEE), 2014, № 15, P. 126-129. (Fialko, N., R. Navrodskaya, G. Gnedash, G. Presich, A. Stepanova, S. Shevchuk).
4. Jeong K. Analytical modeling of water condensation in condensing heat exchanger - Int. J. Heat Mass Transfer, 2010, № 53, P. 2361-2368. (Jeong, K., M. Kessen, H. Bilirgen, E. Levy).
5. Sigal A. Effect of moisture in the blown air on the efficiency of the boilers of industrial and municipal energy - Thermal Power Engineering, 2004, № 12, P. 34–37. (Sigal, A.).
6. Buharkin E. On the issue of improving the environmental performance of gas-using facilities - Industrial Heat Engineering, 2004, № 6, P. 40-42. (Buharkin, E.).
7. Jia L. Effects of water vapor condensation on the convection heat transfer of wet flue gas in vertical tube - Int. J. Heat Mass Transfer, 2001, № 44, P. 4257-4265. (Jia, L., X. Peng, Y. Yan, J. Sun, X. Li).
8. Levy E. Recovery of water from boiler flue gas, 2008, DOE Award Number DE-FC26-06NT42727 (Levy, E., H. Bilirgen, K. Jeong, M. Kessen, Ch. Samuelson, Ch. Whitcombe).
9. Rączka P. Projektowanie kondensacyjnego wymiennika ciepła odpadowego - Rynek Energii, 2014, № 111, P. 87-92.( Rączka, P., K. Wójs).
10. Thermal calculation of boiler units. Normative method, Moscow, Energiia, 1973.
11. Fialko N. Peculiarities of the calculation procedure for surface heat-exchangers of condensation type - Industrial Heat Engineering, V. 22, 2000, № 2, P. 49-53. (Fialko, N., V. Gomon, R. Navrodskaya, V. Prokopov, G. Presich).
12. Dashevskii Yu. Some environmental aspects of the implementation of environmental and energy-saving technologies at TPPs - Thermal Power Engineering, 1991, № 4, P. 61–63. (Dashevskii, Yu., B. Novikov, L. Hasanov-Agaev).

# LOW-TEMPERATURE DISTRICT HEATING WITH DECENTRALIZED GENERATION BY HEAT PUMPS AT A RAILWAY STATION: OPTIMIZING THE SYSTEM AND CALCULATING GREENHOUSE GAS EMISSIONS

Eng. Chicherin S
Omsk State Transport University, Omsk, Russia
man_csv@hotmail.com

***Abstract:*** *This paper discusses a heat pump subsystem within an existing high-temperature DH system located at a railway station in Omsk, Russia. The goal is to increase the efficiency of an existing high-temperature DH system by describing decentralized heat generation from an environmental point of view. We obtain a balance method whereby the heat loss (or the thermal energy loss) is expressed dependent on the supply and return temperatures so as to reduce operating costs of heat supply. The outcome of calculating the heat loss by this method is a relation that is valid typically for all DH networks. Findings beneath show that switching to a low-temperature DH can decrease operating costs and increase overall heat production efficiency. The reason for the latter is a known logarithmic heat flux-temperature correlation. This paper concludes that the idea of decentralized generation has a great potential for the future, as the implementation of this concept is closely related to a low-temperature DH.*

**Keywords**: DISTRICT HEATING; NETWORK; OPERATION; TEMPERATURE

## *1. Introduction*

Although district heating networks have a key role to play in tackling greenhouse gas emissions associated with urban energy systems, little research has been carried out on district heating (DH) networks expansion and integrating decentralized thermal energy generation[1].

Ideas of low-temperature DH [2] with decentralized generation by means of heat pumps [3] are running high. Nevertheless, Bolonina et al. [4] found some reasons to increase network temperature curves. Albeit the paper [5] figures out a leak detection method based on the idea of total metering, which suits well the concepts of 4th generation DH, it emphasizes hydraulic rather than thermal concerns. Zarin Pass et al. [6] contributed the industry a lot by putting effort into a thermodynamic analysis of a novel bidirectional district heating and cooling network. Petrovic et al. [7–9] studied heat demand (load) fluctuations. On the one hand, Petrichenko et. al. [8] have developed a model for short-term thermal load prediction. On the other hand, Verrilli et al. [9] made longer-term forecasting possible.

Guy et al. [10] have made publicly available their development forecasts for a certain DH system (Hague), which is similar to what we are doing. Latosov et al. [11] solely address the issue of parallel energy use with no emphasis on parallel energy production. See Ref. [12] for an overview of fast simulation of district heating and cooling networks. Wu et al. [13] proposes that DH systems consist of CHP units, electrical boilers, and thermal storage facilities, but excludes heat pumps. Akhmetova et al. [14–16] describe existing high-temperature systems though being helpful with heat loss calculation.

The resulting optimization problem shown below is a Linear Programming (LP) problem that can be generalized to become a Mixed Integer Linear Programming (MILP) for which lots of general, robust and scalable approaches exist. The framework presented in this article is particularly based on a Microsoft Office Excel sheet and the Visual Basic for Applications macro language. By way of contrast, Austrian-Swedish researchers [17] have based their solution on the Modelica simulation language and the Python scripting language.

Refs [18] и [19,20] do not seem well matched to key topics of European science, namely advanced engineering and environmental technologies. Like in our research, Operation & Maintenance (O&M) is the topic of [21], but that paper dwells upon building-scale heat distribution systems. Simonovic et al. [22] and Geysen et al. [23] present a sophisticated but promising approach utilizing Artificial Neural Networks (ANN) and using machine learning and expert advice respectively.

## *2. Materials and Methods*

We first discuss the use of a heat pump in a centralized DH system (fig. 1).

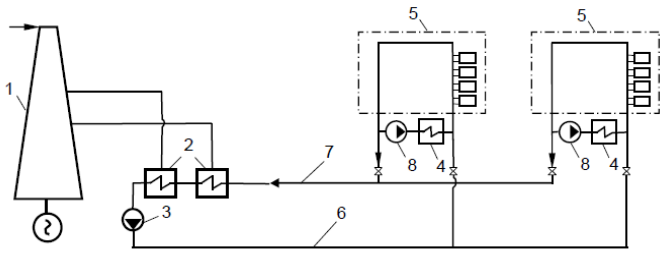



***Fig. 1*** *Illustration of the district heating network configuration used in this research: (1) steam turbine with an off-take, (2) main heat exchangers, (3) DH network pump, (4) local heat sources, (5) consumer interconnection, (6) heat network supply, (7) heat network return, (8) consumer pump*

A heat-pump system configuration can be categorized as open-loop or closed-loop. In an open-loop system, water is withdrawn from a surface water body, passed through a heat exchanger, and then returned to the surface water body. Closed-loop systems circulate the same water between a heat exchanger and the environment. Open-loop systems may be used in almost any application including urban construction, and sub-urban buildings, both DH and district cooling systems. However, we dwell upon economics of scale and therefore consider four ground-source heat-pump systems integrated into urban infrastructure. Georg K. Schuchardt [24] applied similar concept but his system consisted of decentralized thermal storages.

Such implementation creates a low-temperature concept [2] ensuring heat pump operation with the most efficient coefficient-of-performance values. Historically all DH systems have been “unidirectional”, meaning that the water in each pipe segment only flows in one direction. Separate circuits are needed for heating and cooling. In this paper we refer to a ‘bidirectional distribution’ system [6] as one in which water in each pipe segment can flow in alternating directions, depending on the net thermal fluxes on the system. In this case, there is a single network for both DH and district cooling.

For the sake of simplicity, we consider all the buildings being Thermostatically Controlled Loads (TCLs) as in [25] or [26] thus the amount of heat produced matches the amount of heat required at each moment of time t. A consumer interconnection (fig. 1, 5) is assumed to be typical even though simulation results show that controllers tuned to specific operating conditions can’t ensure operation stability of heating substation if operating conditions vary in a great range [27].

The minimization problem is solved by means of Mixed Integer Linear Programming (MILP). Numeric values are obtained by means of a Microsoft Office Excel sheet and the Visual Basic for Applications macro language. See Ref. [17] for an overview of different numerical optimization methods. The only operating costs are heat losses and electricity consumption, others are neglected.

What is crucial is the rate of heat flow through the pipe at the position x, and the moment of time t. There are the two terms on the right-hand side of the equation related to the thermal energy loss corresponding to the advective contribution (which may also be called mass or hydraulic contribution) and convective contribution (the turbulent one) [16]. M. Chertkov and N. Novitsky measured heat-flow rate in Watts, however we represent a heat loss measured in Gcal/h. Heat carrier fluid density and the area of the pipe cross-section are taken into account. We also make a comprehensive assessment of the heat carrier (water), eventually re-using their method. For the present paper as in [23] a certain area (fig. 2) was used as a case study.

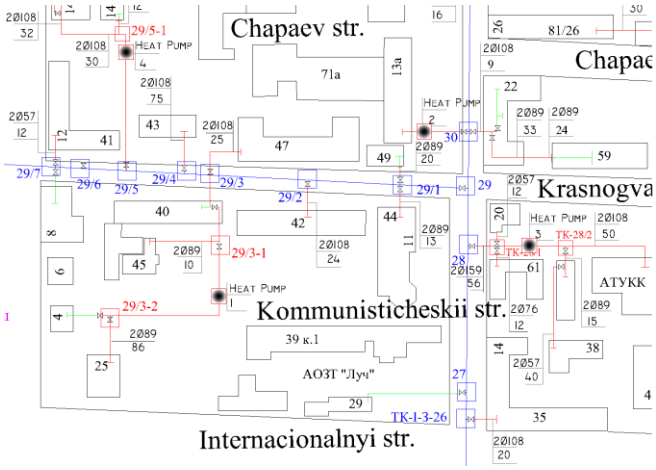



***Fig. 2*** *Chart of the investigated district*

Hereafter we describe a 41.2 MW district heating system at a railway station in Omsk, Russia, that utilizes a heat pump and coal-fired CHPP to supply heat to a heating district. With ammonia as the refrigerant, the three-stage heat pump is able to supply hot water for a maximal heat output of 10 MW and a designed heat pump coefficient of performance of 3, using groundwater as its source.

The piping in the network is about 392 m in length, with a total volume of about 64 m3. The transmission lines (the blue ones in the figure) became operational in 1988 and are currently fed by CHPP #5 with a coal burner. In 2004, the main part (the red one in the figure) was retrofitted to work with lower operating temperature. Another (green) part is to be installed this year with a capacity of 0.7 MW.

The supply temperature used was based on a conventional linear relationship of the outdoor temperature [21] taken from a data set with actual data [28]. A supply temperature of 78 C was first used to simulate the conventional high-temperature DH system in our calculations. Then we studied the energy efficiency of a multisource system where supply temperatures of 62 and 57 C were used for modeling. For the simulation of an ultra-low-temperature DH system, supply temperatures of 41 and 39 C were used. [21] The given approach is still being modified: ANN [22] and using machine learning and expert advice [23] are probably coming in the future.

## *3. Results and Discussions*

Figure 3 shows the investigated relation of operating costs (thermal energy losses) and environmental impact of pollutions that could be served with DH at a given constraints in a commercially mature way.

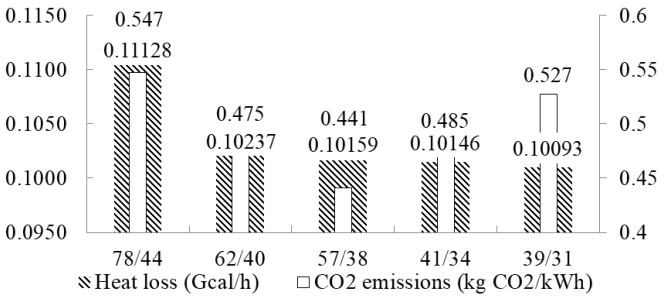



***Fig. 3*** *Spectrum of heat losses and CO2 emissions vs. supply/return temperature*

The 57/38 curve ended up being the optimal solution because lower temperatures force heat pumps to operate with a coefficient of performance (COP) outside its best range. This results in greenhouse gas emissions increasing up to 0.527 kg CO2/kWh in case of 41/34 and 39/31 curves; moreover, heat losses stop to decrease significantly at such curves. The reason for latter is a known logarithmic heat flux-temperature correlation. These results are in good agreement with other studies which have shown that heat losses in Russia [14] are basically higher than, for instance, in Europe and Czech Republic [15]. Moreover, calculation of GHG emissions outlines that the values obtained are similar with the average European $CO_2$ emission factor.

## *4. Conclusions*

Calculating heat losses by the approach herein presented has resulted in a relation that is valid typically for all DH networks. We have considered the technical aspects such as the energy performance of a heat pump as well as the environmental ones (e. g. the evaluation of the greenhouse gas emissions for this or that temperature performance). Findings beneath show that switching to a low-temperature DH can decrease operating costs and increase overall heat production efficiency. Therefore, in the situation where Thermostatically Controlled Loads (TCLs) are introduced, the novel DH system (with lower temperature) becomes the most efficient option due to heat losses dropping from 0.11128 to 0.101159 Gcal/h in the optimal case. We have tried to show that the idea of decentralized generation has a great potential for future, because the implementation of this concept is closely related to a low-temperature DH. With the development of energy efficient networks and renewable-energy facilities at railway stations, railway companies will be definitely interested in lowering the temperature parameters of a distribution system, as it can decrease CO2 emissions by more than 23% as in the case study.

## *Acknowledgements*

This research was supported by the Government of the Russian Federation under Project No. 860 (Decree dated August, 8 2017). The Author thanks Russian Railways ('RZhD', JSC) for cooperation and kindly provided information. The Author would like to acknowledge the valuable comments and suggestions of the reviewers, which have improved the quality of this paper. The Author also expresses gratitude to the unnamed editor who has proof-read and edited the text.

## *References*

1. Delangle, A., Lambert, R. S. C., Shah, N., Acha, S. & Markides, C. N. Modelling and optimising the marginal expansion of an existing district heating network. Energy 140, 209–223 (2017).

2. Ziemele, J., Pakere, I., Chernovska, L. & Blumberga, D. Lowering Temperature Regime in District Heating Network for Existing Building Stock. Chem. Eng. 52, 709–714 (2016).

3. Goodier, C. I., Chmutina, K., Poulter, E. & Stoelinga, P. Potential for seawater district heating and cooling in the UK. Proc. ICE - Energy 3, 1–5 (2013).

4. Boloņina, A., Boloņins, G. & Blumberga, D. Analysis of the Impact of Decreasing District Heating Supply Temperature on Combined Heat and Power Plant Operation. Environ. Clim. Technol. 14, 41–46 (2014).

5. Valinčius, M., Vaišnoras, M. & Kaliatka, A. Study and demonstration of pressure wave-based leak detection in a district heating network. Struct. Infrastruct. Eng. 14, 151–162 (2018).

6. Zarin Pass, R., Wetter, M. & Piette, M. A. A thermodynamic analysis of a novel bidirectional district heating and cooling network. Energy 144, 20–30 (2018).

7. Petrović, J. R., Gvozdenac-Urošević, B. D. & Polc, J. J. Reasons for heat demand changes and effects on planning and development of heating systems. Therm. Sci. 16, 63–77 (2012).

8. Petrichenko, R., Baltputnis, K., Sauhats, A. & Sobolevsky, D. District heating demand short-term forecasting. in 2017 IEEE International Conference on Environment and Electrical Engineering and 2017 IEEE Industrial and Commercial Power Systems Europe (EEEIC / I&CPS Europe) 1–5 (2017). doi:10.1109/EEEIC.2017.7977633

9. Verrilli, F. et al. Model Predictive Control-Based Optimal Operations of District Heating System With Thermal Energy Storage and Flexible Loads. IEEE Trans. Autom. Sci. Eng. 14, 547–557 (2017).

10. Guy, S., Sheriff, G., Chmutina, K. & Goodier, C. I. in Actor Networks of Planning Exploring the Influence of Actor Network Theory (ed. Rydin, Y. and Tate, L.) 142–156 (Routledge, 2016).

11. Latosov, E., Volkova, A., Siirde, A., Kurnitski, J. & Thalfeldt, M. Methodological Approach to Determining the Effect of Parallel Energy Consumption on District Heating System. Environ. Clim. Technol. 19, 5–14 (2017).

12. del Hoyo Arce, I. et al. Models for fast modelling of district heating and cooling networks. Renew. Sustain. Energy Rev. 82, 1863–1873 (2018).

13. Wu, C. et al. Combined Economic Dispatch Considering the Time-Delay of District Heating Network and Multi-Regional Indoor Temperature Control. IEEE Trans. Sustain. Energy 9, 118–127 (2018).

14. Akhmetova, I., Chichirova, N. & Derevianko, O. Revisiting heat losses calculation at district heating network. Int. J. Civ. Eng. Technol. 8, 694–702

15. Čarnogurská, M., Dobáková, R. & Priihoda, M. Application of dimensional analysis in heat loss determining in district heating systems. Acta polytech. 56, 81 (2016).

16. Chertkov, M. & Novitsky, N. N. Thermal Transients in District Heating Systems. Energy (2018). doi:10.1016/j.energy.2018.01.049

17. Schweiger, G., Larsson, P.-O., Magnusson, F., Lauenburg, P. & Velut, S. District heating and cooling systems – Framework for Modelica-based simulation and dynamic optimization. Energy 137, 566–578 (2017).

18. Kim, Y.-S. & Kim, J.-G. Failure analysis of a thermally insulated pipeline in a district heating system. Eng. Fail. Anal. 83, 193–206 (2018).

19. Chicherin, S. V. Unlocking a potential of district heating network efficient operation and maintenance by minimizing the depth of a trench system. Bull. Tomsk Polytech. Univ. Geo Assets Eng. 328, (2017).

20. Chicherin, S. V. New approach to determination of corrosion damage degree of pipeline system elements. Bull. Tomsk Polytech. Univ. Geo Assets Eng. 327, (2016).

21. Jangsten, M., Kensby, J., Dalenbäck, J.-O. & Trüschel, A. Survey of radiator temperatures in buildings supplied by district heating. Energy 137, 292–301 (2017).

22. Simonović, M. B., Nikolić, V. D., Petrović, E. P. & Ćirić, I. T. Heat load prediction of small district heating system using artificial neural networks. Therm. Sci. 20, 1355–1365 (2016).

23. Geysen, D., De Somer, O., Johansson, C., Brage, J. & Vanhoudt, D. Operational thermal load forecasting in district heating networks using machine learning and expert advice. Energy Build. 162, 144–153 (2018).

24. Schuchardt, G. K. Integration of Decentralized Thermal Storages Within District Heating (DH) Networks. Environ. Clim. Technol. 18, 5–16 (2016).

25. Claessens, B. J., Vanhoudt, D., Desmedt, J. & Ruelens, F. Model-free control of thermostatically controlled loads connected to a district heating network. Energy Build. 159, 1–10 (2018).

26. Vanhoudt, D., Claessens, B., Salenbien, R. & Desmedt, J. The use of distributed thermal storage in district heating grids for demand side management. (2017).

27. Wang, Y. et al. Operation stability analysis of district heating substation from the control perspective. Energy Build. 154, 373–390 (2017).

28. Chicherin, S. District Heating System Performance Charasteristics (Omsk, Russia, Nov. 2017). Mendeley Data, v1 (2017). doi:10.17632/4tgypy6hhf.1

.

# THE ENVIRONMENTAL CONDITIONS IN THE NEIGHBOURHOOD AND ON THE SURFACE OF THE INTERNATIONAL SPACE STATION: PART TWO

Ass. Prof. Miteva A. M. [1], Assoc. Prof. Dr. Karaguiozova Z. K. [1], Ciski A. [2], Cieślak G. [2]
Space Research and Technology Institute, Bulgarian Academy of Sciences, Sofia, Bulgaria [1]
Institute of Precision Mechanics, Warsaw, Poland [2]

ad.miteva@gmail.com [1], karazuzi@yahoo.com [1], aleksander.ciski@imp.edu.pl [2], grzegorz.cieslak@imp.edu.pl [2]

***Abstract:*** *When it comes to space vehicles for humans (as the International Space Station), the most important goal is how to achieve safety in the space vehicles, that people should survive their travel to space and return safely, in good health. In this connection, the primary role of the space materials science is to ensure the long-term trouble-free operation of materials and elements of equipment in a space environment. In this paper we present the second part of the brief analysis of some different aspects of the space environment and their effect on the properties of materials which are located or are mounted on the body of the International Space Station.*

**Keywords**: INTERNATIONAL SPACE STATION (ISS), LOW-EARTH ORBIT, COSMIC RAYS, GAMMA RADIATION, CRYSTALLINE STRUCTURE, COATINGS, METAL ALLOYS, VACUUM, SPACE APPLICATIONS, SPACE ENVIRONMENT

## *1. Introduction*

In this paper we present a brief overview of the analysis of different aspects of the space environment and their effect on the properties of materials, which are located or are mounted on the body of the ISS (or a spacecraft, or a satellite in the low Earth orbit) (Fig. 1). This is the next, second part of our previous paper „The environmental conditions in the neighbourhood and on the surface of the International Space Station: part one“ [1].



***Fig. 1*** *International Space Station and the Earth [2,3].*

## *2. Conditions around and on the body of the ISS*

It is a true miracle that we have such the extremely harsh and unfriendly environment surrounding us from all corners of space. Indeed our planet is a fantastic exception relative to what we know of the universe. We must continue to learn about the environment in space and how to overcome the challenges surrounding us, in order to learn how to live safely outside of our Earth. These are many harsh factors – gravity, vacuum, neutral particles, plasma, micrometeorites, space debris, radiation etc. in our space environment.

### *2.1. Radiation: Effects*

We are going to talk about the radiation sources in space and the dangerous of radiation. The main types of penetrating corpuscular radiation in space are electrons and protons trapped of the Earth's radiation belts, galactic cosmic rays (GCR) and solar cosmic rays (SCR) already familiar to us [4-11].

There are several risks - health risks (these risks are not our subject) and also some other risks. For electronics, radiation can cause signal event upset, which is a change of state caused by one single ionizing particle striking a sensitive node in a micro-electronic device, such as in a microprocessor, semiconductor memory, or power transistor, which can cause computers to malfunction. There have been cases where it was fairly sure that the problem like this led to loss of a space mission and a satellite.

Continuous radiation also degrades the solar arrays, which is another problem. In addition to the ionizing particles that we have talked about, there is very intense ultraviolet (UV) light from the Sun in space to the ISS. UV radiation, which does not affect materials on the ground, because it is filtered out by the atmosphere, can damage most organic materials, like polymers. This, together with the effect of vacuum on materials, makes material selection for space quite hard. Lastly, solar radiation also creates a force on any surface that is exposed to it. We call it the "solar radiation pressure". This force is small but continuous, and it creates a perturbation that can take our satellite out of its intended orbit, if we do nothing about it. This force can, however, be used for something practical: we can build, for example, "solar sails", which are very large surfaces that can be deployed in space, to use this force and travel for free, without consuming any propellant. This is a technology that is currently under study.

All radiation changes that occur in the materials and elements of the apparatus can be divided into reversible and irreversible. Reversible changes occur in the materials during irradiation and almost completely disappear after it is discontinued. Irreversible changes continuously accumulate during irradiation and are retained completely or partially after the irradiation has ceased. Changes of the first kind are mainly due to ionization and excitation of the atoms of the substance, changes in the second type - with the formation of radiation defects.

Let us consider how the changes of both types arise in semiconductor devices [9].

Charged particles, braking in a solid, produce ionization of atoms, and electrons separated from atoms can freely move in it. The ions formed are deprived of this possibility - they are firmly held together by bonds in the crystal lattice. However, each ionized atom can capture an electron of an adjacent neutral atom, as if "transferring" its ionized state to it. When an external electric field is applied, the process of moving the ionized state in the crystal lattice occurs in a direction opposite to the direction of motion of the electron and is equivalent to the displacement of an elementary positive charge (hole). Two elementary charges of the opposite sign are formed in a solid in the ionization of an atom-an electron and a hole (an electron-hole pair is formed). Electrons and holes can be created in semiconductors and in another way - by introducing into the main material impurities that form in it either additional free electrons or, conversely, holes. In the first case, it is said that the semiconductor material has electron conductivity, or n-type conductivity, in the second case it is hole conductivity, or p-type conductivity.

If two semiconductor materials with opposite conductivity types are brought into close contact, a double electric layer is formed near the contact plane, the so-called *pn* junction, which has rectifying properties, i.e., the ability to transmit electric current only at one polarity of the external voltage applied to the *pn* junction. The work

of most semiconductor devices is based on the rectifying action of the *pn* junction. Thus, one of the consequences of the effect of radiation on semiconductor devices is an increase in the reverse current of *pn* junctions upon irradiation, which can worsen instrument parameters. The effect of increasing the reverse current of the *pn* junction upon irradiation finds also a useful application: semiconductor detectors of ionizing radiation work on this principle. Most often, the currents created by cosmic radiation in semiconductor devices directly upon irradiation are small and do not significantly affect the operation of electronic equipment. More important are irreversible changes, manifested in the gradual deterioration of the parameters of semiconductor devices: a decrease in amplification, a reduction in the permissible operating voltages, etc. These changes, as already noted, are due to the accumulation of radiation defects in semiconductor materials. Radiation resistance of semiconductor devices is evaluated mainly by irreversible effects, which can eventually lead to failure or complete failure of the device. A failure is considered to be the departure of the main monitored parameter of the device from the set interval of admissible values. Different optical materials have relatively low radiation resistance. The assortment of optical elements used onboard the ISS/spacecraft is extremely wide: portholes, lenses, prisms, light guides, input windows of photoelectronic devices, elements of laser technology, etc. The main effects caused by cosmic radiation on optical materials are luminescent luminescence and staining. The first effect is reversible, the second - irreversible. Under the influence of radiation, ionization and excitation of atoms of optical materials occur. The excess energy reported to the atoms is largely released by emitting photons of light in the visible part of the spectrum. Such a luminescence, excited by ionizing radiation, is called radioluminescence. We should particular mention the case of radioluminescence of optical elements under the action of heavy GCR nuclei. When they hit a luminescent optical material, there is an intense light flash, called phosphene. Phosphenes create significant impulse noise for optical equipment and optoelectronic devices. Staining of optical materials under the action of cosmic radiation occurs due to the ionization of atoms and the appearance of radiation defects. The free electrons and holes that appeared in the material upon irradiation can be captured by radiation defects. Thus, the so-called colour centers are formed, which both change the optical properties of the material. The problem of radiation dyeing is especially important for fibre optics used in space equipment, since the length of fibre communications can reach tens and hundreds of meters and the effect of radiation reduction of the transparency of the fibre will greatly affect the quality of the transmitted information.

The task of protecting the crew and spacecraft equipment from the effects of radiation is one of the most important in the preparation of space missions. The main method of protection is the absorption of radiation by the shell of ISS. Even a relatively thin aluminim wall significantly reduces the radiation dose in the inner compartments. The so-called active methods of protecting the ISS/spacecraft with the help of electric or magnetic fields that divert charged particles from the apparatus are also being developed.

Protons from SCR pose a danger for astronauts and for flights in near-earth orbits, although much less than during interplanetary flights. The fact is that the main part of SCR protons is deflected by the Earth's magnetic field to the poles and there it is absorbed in the atmosphere, penetrating to altitudes of several tens of kilometres. At medium and especially equatorial latitudes only protons of the highest energy can penetrate through the magnetic field, which are relatively few in the composition of SCR.

If an extremely powerful solar flare happens, there are two possibilities: (a) - to take refuge in the descent vehicle of the Soyuz spacecraft, which thick heat-insulating walls create reliable protection against radiation; (b) - during the time of the motion of SCR protons from the Sun to the Earth, take measures to lower the ISS/spacecraft from the orbit.

### *2.2. Heavy nuclei*

Electrons and holes formed when a fast charged particle hit a semiconductor device create an electric charge inside it, and their motion in an electric field causes a current pulse. This effect is based on the work of charged-particle detectors, that is, the effect is useful for detectors. However, for transistors and integrated circuits operating in various electronic devices of ISS (or spacecraft), similar phenomena serve as a source of impulse noise. If the amplitude of the interference signal is comparable to the amplitude of the operating signals of the semiconductor device, a false alarm can occur in the device that includes the device (for example, the trigger will switch, the state of the memory cell will change, etc.). Such phenomena are usually called functional malfunctions, among which, in particular, information malfunctions in the memory cells of a computer.

At the heart of functional failures, therefore, are reversible changes in the parameters of semiconductor devices. A distinctive feature of such a failure, which distinguishes it from other phenomena associated with the action of corpuscular radiation, is that it is caused by a single charged particle when it enters a semiconductor device. While the gradual degradation of instrument parameters associated with irreversible effects is a consequence of the impact of a large number of particles.

Two conditions are necessary for the appearance of a functional malfunction: a sufficiently large value of the charge created inside the semiconductor device by the incident particle, and not too long an ionization track (to collect electrons and holes more fully at the electrodes of the device). It follows that such failures can be caused only by particles having a sufficiently high energy and at the same time a small mean free path in the semiconductor material.

Of the various types of cosmic corpuscular radiation, the heavy GCR nuclei satisfy these requirements to the greatest extent (see Table 3 [1]). Due to their very high initial energy, the GCR particles penetrate the shell of the ISS, the protective casings and the instrument housings and can get into the semiconductor material at the end of the run, having significantly lower energy, but just such that it is effectively inhibited and produce intense ionization in a thin layer of semiconductor material.

According to the available estimates [9,10], the probability of a heavy GCR core falling into the active region of a semiconductor device during one day of space flight is approximately $10^{-5}$. However, computers installed on board modern ISS/spacecraft already contain about $10^5$ semiconductor devices, that is, in their totality they are potentially exposed to one functional malfunction per day due to the effect under consideration. But there is a steady trend towards a further increase in the volume of electronic equipment on board the ISS/spacecraft. The Space Station is really run by computers. The computers are also connected to a lot of sensors, which sense the status of many, many systems of ISS.

The problem of functional failures in electronic equipment under the action of single charged particles has arisen as a result of progress in the field of semiconductor instrumentation technology. The creation of modern semiconductor chips with a very high degree of integration, on the one hand, led to a decrease in operating voltages and currents, and on the other - to a sharp increase in the number of elements susceptible to malfunctions in the equipment.

### *2.3. Solar Panels*

Solar batteries - the main sources of electricity on modern spacecraft - consist of a large number of semiconductor photoconverters, or, as they are called, solar cells. All the electrical power on ISS also comes from the solar arrays.

The theoretical coefficient of conversion of solar energy into electrical energy (photoconverter efficiency) can reach 22%. The efficiency of photoconverters actually used on the spacecraft is still about half lower. The operating parameters of the photoconverter, including the efficiency, depend strongly on the completeness of the

collection of electrons and holes formed on the electrodes by the light. Various defects of the structure of a semiconductor material (the material without defects at all is impossible to fabricate), as well as defects that arise under the action of cosmic radiation, capture a part of the electrons and holes as they move toward the electrodes, which leads to a deterioration in the parameters of the transducer.

Since power supply is one of the key factors in ensuring the normal functioning of ISS/spacecraft, considerable efforts have been made to study the radiation resistance of photoconverters and to develop ways to protect them against the effects of cosmic radiation. The simplest and most effective way to increase the radiation resistance of solar batteries was the use of optically transparent protective coatings, which do not allow passing a significant part of the incident corpuscular stream. As such a "shield" for solar cells, quartz and glass plates 0.1 - 3 mm thick are used. The thickness of the plates is chosen on the basis of compromise considerations: to provide a sufficiently effective protection of solar cells with a minimum increase in mass; structure. According to available data, the use of protective coatings makes it possible to increase the radiation resistance of solar batteries 100-1000 times.

In addition to radiation degradation, the characteristics of solar panels can deteriorate due to the already discussed process (see [1]) of contamination of the protective glass surface with own external atmosphere (OEA) products.

### *2.4. Micrometeoroids*

Now we will talk about micrometeoroids. The goal is to understand what we mean by these concepts, how many there are of these in space, and what mitigation strategies can be used to decrease the risk of damage to ISS/spacecraft. We will start with a few definitions. First we have meteoroid, which is a small particle from an asteroid or comet, orbiting the Sun. A meteor is a meteoroid that is observed as it burns up in the Earth's atmosphere, also known as a shooting star. A meteorite is a meteoroid that has survived its passage all the way to the Earth's atmosphere, and impacts the Earth's surface. So, we have to distinguish the difference between meteoroid, meteor and meteorite. The ones that hit you in space are the meteoroids. Near Earth Object or NEO are asteroids or comets that orbits around the Sun at very close proximity to Earth's orbit, and could actually risk hitting the Earth sometime in the future.

Micrometeoroids are very small meteoroids, about a millimeter in size, and less than a gram in mass. Due to its very high speed, on the order hand, of the order of 10km per second micrometeoroids can be a danger to a spacecraft. They constantly degrade the outer casing of a spacecraft in a manner analogous to sandblasting. During meteor showers sometimes there is the risk that larger micrometeoroid pieces could damage the heat shield, or other parts of ISS. We can note that 10-40,000 tons of micrometeoroids per year fall on Earth. That is a lot, while meteoroids are out there, they are not caused by anything humans have done.

### *2.5. Space debris*

Space debris is completely created by humans. Space debris is leftover pieces from launchers, dead satellites, and other things, which have been left up in space, orbiting, and that we cannot control. Sometimes they collide, and create even more space debris pieces. By now, we estimate that there are about 20000 pieces of space debris larger than 5 cm in size orbiting the Earth, which can be tracked from Earth. We know roughly how many there are and approximately where they are. There are, however, another 300000 pieces smaller than 1cm, at below 2000 km altitude. These pose an increasing danger for satellites and space vehicles up there. Space debris is constantly increasing, and they are also putting more and more satellites up there, so this is a growing problem.

Unfortunately, we do not yet have a good idea for how we can actually clean up the space debris. So what can one do to protect our spacecrafts? One thing is to calculate the risks, depending on the sizes and the speeds the micrometeoroids and space debris and then put shields on the outside of the spacecrafts.

This is actually what has been done on the Space Station. Since the early years of the Space Station, the Americans determined that there was a need for some more shields on the Russian part of the ISS to make sure the risk over the long lifetime of the Space Station, would be low enough. So they added extra shields on the outside of some parts.

The other thing that can be done is to track all debris the size of a fist and bigger, and if anything risks coming in the vicinity of 1km of ISS, then you can do a collision avoidance maneuver. You can give the Space Station a little boost to push it up, or possibly even bring it down, to get out of the collision area. There have been a few instances where there has not been enough time to do this maneuver, and in these cases, the crew has been asked to sit in the Soyuz capsule during the time when they could possibly have had a collision. If there is a collision they could have left the Space Station immediately, if there is no way to save it.

These are the two risks in space from matter that can possibly collide with the spacecraft - micrometeorids and space debris.

The micrometeoroids are all over in space, whereas space debris is only a problem in the orbit around the Earth. To protect spacecraft, we can put up shields to make the walls thicker and that will help. And secondly, we can try to avoid a collision if the matter is detected early enough.

### *2.6. Plasma*

Plasma is the fourth state of matter, after solid, fluid and gas. If it gets hot enough, the matter gets completely, fully ionized. And it is a mixture of electrons and protons, mainly of equal amount. In total, it is neutral. Actually 99% of the universe consists of plasma. The solar wind carries plasma, and bound to it are magnetic fields. There are not a lot of particles there, about 10 particles per cubic centimeter, but the issue is that spacecraft can get charged by the plasma, which can disturb communications and can disturb instruments. It is a hazard when doing space walks and dockings, where there is a risk for discharges. On the ISS the risk is increased by the huge solar arrays, which can have up to 160 volts. Due to this, we have taken some measures to try to "ground", so to say, the ISS towards the space. This is done with a special device called a Plasma Contactor Unit, which controls the voltage between the Space Station structure and the local plasma. And before you allow astronauts to go on space walks, you have to make sure that at least one PCU - Plasma Contactor Unit - on the Space Station works.

We talked about vacuum, that there still are atoms and molecules around out there in space, in low earth orbit in particular and they will exert some drag force in low earth orbit, so spacecraft will not stay there forever unless one gives them a boost now and then, and that plasma that comes in the solar wind is another danger in space.

### *2.7. Neutral particles*

In space it is not a perfect vacuum, we have what is called, neutral particles, still in low Earth orbit, roughly between 100 to 2000 km altitudes. There are some nitrogen molecules up to about 100 km, but of bigger concern is atomic oxygen from 100 to some 700 km. Atomic oxygen is a particularly aggressive chemical, so it can cause surface erosion and degradation of many materials. The second effect of neutral particles, or remainder of atmosphere, is that they exert a drag force on the space vehicle. The drag force $F$ (see formula (1)) is given by the density of the medium we are in, which is proportional to the pressure - times the surface area perpendicular to the velocity, called A, times the velocity $v$ squared, and there is also times some drag coefficient, called $C_D$ [3,4]

(1) $F = S.A.v^2 C_D$.

This force (1), which acts against the velocity vector, has a slowly braking effect, and eventually leads to an orbit altitude loss. The International Space Station typically loses around 150 to 100 m of altitude per day. The altitude loss, converts into the lifetime of a spacecraft in orbit. The lifetime in space increases very quickly with altitude because the pressure falls quickly.

The low-density spacecraft, with 25 kg per square meter, at 300 km altitude will only survive about two weeks in orbit. While if ISS moves up towards a bit over 500 km altitude, you can stay there for a year. When you reach about 700 km, you could stay there for about 15 years. If you have a more high-density spacecraft, like 100 kg per square meter, then it could stay longer with a factor of 4 to 5.

### *2.8. Secondary-emission processes*

The electrons incident on the plate (of some material) in vacuum knock out the so-called secondary electrons from its near-surface layer, which leave the plate and fly out into the vacuum. This phenomenon is called secondary electron emission. Thus, through the surface of the plate, two electron streams are directed towards each other: the flux of electrons incident on the plate (primary) and the flux of electrons leaving the plate (secondary). The value equal to the ratio of the current of secondary electrons to the current of primary electrons, the secondary electron emission coefficient, can be either smaller or greater than unity. The magnitude of the secondary electron emission coefficient depends on the kind of material, the degree of purity of its surface, the energy of the primary electrons and on some other less significant factors. With an increase in the energy of primary electrons, the coefficient of secondary electron emission first increases, and then, after reaching a certain maximum value, begins to decrease. For metals, the maximum value of the secondary electron emission coefficient is usually 1 - 1.5 and is achieved at primary electron energies of about 500 eV. Dielectrics, as a rule, have a higher coefficient of secondary electron emission in comparison with metals. When electrons are bombarded with ions, electrons are also knocked out-secondary electron emission under the action of ions, or ion-electron emission. Simultaneously, a certain amount of ions is knocked out of the surface-secondary ionic or ion-ion emission occurs. In outer space corpuscular streams different in composition and energy act on the ISS/spacecraft. Therefore, on the surface of the spacecraft, all the listed processes proceed simultaneously, the intensity of each of which depends on the characteristics of the irradiating radiation.

It is important to note that the change in the state of the material surface inevitably entails a change in their secondary emission properties under the action of a space factors (cosmic vacuum, particles from OEA, corpuscular fluxes, ultraviolet radiation).

From the illuminated areas of the surface of the ISS, photoelectron emission occurs - the emission of electrons under the action of solar electromagnetic radiation (mainly ultraviolet). The current density of photoelectron emission from the surface of the spacecraft is $(1 - 5).10^{-5}$ A/m$^2$.

Secondary-emission processes can directly affect the operation of on-board ISS/spacecraft equipment, creating extraneous currents in sensitive sensors of various devices. The role of these processes is very great when electric charges are formed on the surface of a ISS/space vehicle.

## *3. Conclusion*

When it comes to space vehicles for humans (as ISS), the most important goal is how to achieve safety in the space vehicles, that people should survive their travel to space and return safely, in good health. In this connection, the primary role in the implementation of space projects is to ensure the long-term trouble-free operation of materials and elements of equipment in a space environment. The achievements of space materials science are a solid foundation for solving these tasks. We briefly examined some of the problems and tasks that space materials science is dealing with - such as the behavior of materials in high vacuum conditions, the degradation of materials on the surface of ISS and equipment elements [1]., the electrification of satellites, the work of materials in the atmosphere of heavy nuclei, the secondary-emission processes, space debris, micrometeoroids, solar panels, etc. But there are many other aspects of the space environment and their effect on the properties of materials, which are located or are mounted on the body of the ISS, which will be the subject of our next future study.

## *4. Acknowledgements*

This study was partially supported by the bilateral Cooperation Agreements between Bulgarian Academy of Sciences (Space Research and Technology Institute) and between:

- Polish Academy of Sciences (Institute of Metallurgy and Materials Science of Polish Academy of Sciences (with support of the Institute of Precision Mechanics)) - “Optimization of aluminium alloys surface properties with prospects for terrestrial and aero-space applications” and

- University of Mons (Metallurgy Lab) - “Characterization of various electroless nickel coatings (micro and nanostructured) on aluminium alloys suitable for application in terrestrial and aerospace applications”.

## *5. References*

1. Miteva, A., Z. Karaguiozova, A. Ciski, G. Cieślak, The environmental conditions in the neighbourhood and on the surface of the International Space Station: part one, 2018, in print.
2. https://youtu.be/8jjVmWHWLP0.
3. https://courses.edx.org/courses/course-...
4. Norberg, C., H. Steimle, eds. Human spaceflight and exploration. Springer, 2013.
5. Андрюшин, Е. А., А. П. Силин, Физические проблемы солнечной энергетики, УФН, 161, 1991, 129-139.
6. ZINKLE, S. J., Fundamental radiation effects parameters in metals and ceramics, Radiation effects and defects in solids, 1999, 148, 447-77.
7. КАЧАН, С. М., Взаимодействие гамма излучения с веществом, Минск, 2014, 1-37.
8. Buchvarova, M., D. Draganov, Cosmic-Ray Spectrum Approximation Model: Experimental Results and Comparison with Other Models, Solar Physics, 284, 2013, 599-614.
9. http://epizodsspace.airbase.ru/bibl/znan/1983/4/vozdeistvie.html
10. Акишин, А. И, Космическое материаловедение, Методическое и учебное пособие.–М: НИИЯФ МГУ, Москва, 2007, 209.
11. http://profbeckman.narod.ru/YadFiz.files/L14.pdf