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INNOVATIVE ECONOMY: TRENDS AND EVALUATION OF THE EFFECTIVENESS OF INNOVATIVE PROCESSES

Valentina Kundius - Doctor of Economics[1], Professor, Evgeny An - Doctor of Economics[2],
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Head of the Analytical Research Center of Al-Farabi Kazakh National University, Kazakhstan[2]

Summary: *In scientific view, an innovative economy is an economy that is based on knowledge, new achievements in science, technology and highly intellectual capital. The article defines the main components of the innovative economy, each of which reaches a competitive level according to international criteria: first of all, it is innovative potential; institutional innovation system; innovative infrastructure and highly organized forms of interaction of economic entities, including innovation centers, technoparks, technopolises, clusters, venture business and others; favorable environment for human capital growth. In the course of the study, we have given scientific credence to the indicators of innovative development of economy, criteria and indicators for assessing innovative nature of production, innovation activity at the levels of enterprises, organizations, territories, as well as indicators of innovation commitment of economy and the effectiveness of innovative processes.*

KEYWORDS: *INNOVATIVE ECONOMY, INDICATORS OF INNOVATIVE ECONOMIC DEVELOPMENT, CRITERIA, INDICATORS OF INNOVATION LEVEL, EVALUATION OF INNOVATIVE PROCESSES EFFECTIVENESS*

Introduction

Innovative economy is a non-alternative vector of business development, both for separate territories and the whole country, as it ensures their competitiveness in production and in the world markets. Practices of implementing innovative strategies in recent years have shown a lack of administration and investment in certain programs. Innovative economy requires creating the development basis in the unity of the productive forces and production relations in the framework of the general economic environment. At present, the processes of developing innovative economy are constrained by the problems of science financing, modernization of facilities in scientific laboratories and institutes, as well as the problems of training innovative specialists. Undoubtedly, the lag in scientific and technological support of educational process, in its interaction with production, insufficient innovative activity of business in this direction, its low financial capabilities – all have a negative impact. Since innovative processes require investments, in this regard, in the process of their analytical evaluation it is necessary to assess not only the innovative potential and innovative activity of economic entities, but also their economic effectiveness on the basis of integral approach, which requires developing a system of indicators and algorithms for their calculation.

Materials and methods of research

Theory and methodology of the study are based on fundamental works of domestic and foreign economists in the fields of regional economy, distribution of productive forces, theory of integration, concept of national systems of innovation, theory of clusters.

The database of the research has been formed from the official data on economic potential of the Russian regions, in particular, the Altai Territory and the Republic of Kazakhstan, the achievements of science and education, their realization in practice, presented in official statistical editions, on the Internet; materials of personal observations of the authors.

The main research methods are as follows: monographic, system analysis, statistical, abstract-logical, economic-mathematical, system modeling, expert assessments. The research is based on dialectical, system, cluster, business process approaches.

Results and discussion

Studies have shown positive dynamics and acceleration of innovation processes not in all regions of Russia. In the Siberian Federal District, the share of organizations engaged in technological, marketing and organizational innovations in the total number of the surveyed organizations is increasing only in two regions out of twelve – in the Tomsk Region and the Altai Territory (Table 1).

Table 1. *Innovative activity of organizations, %*[*]

	Years			
	2010	2013	2015	2017
Russian Federation	9.5	9.3	9.3	8.5
Siberian Federal District	8.2	9.1	8.0	7.3
Altai Territory	8.2	11.3	12.0	12.8
Novosibirsk Region	5.5	9.9	9.4	7.5
Tomsk Region	18.4	14.6	12.8	14.0

[*]Compiled according to the source [1].

Furthermore, indicators of innovative activity of the organizations in those regions exceed average indicators of the Siberian Federal level and the average Russian (Fig. 1).

However, in the implementation of the strategy of innovative economic development, it is important to determine not only the level of innovative activity in organizations, but, to a greater extent, the effectiveness of innovative processes, investment in innovation, ultimately, the effectiveness of the implementation of innovative strategies. The effectiveness of innovative

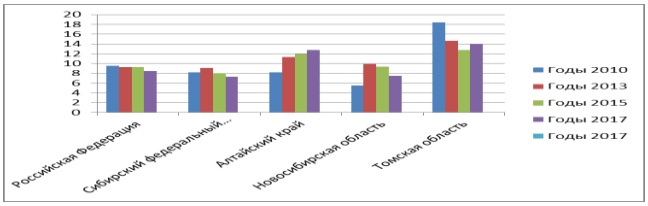

Figure 1. *Innovative activity of organizations, %**

processes is influenced by a large number of factors, which are schematically presented in Fig. 2.

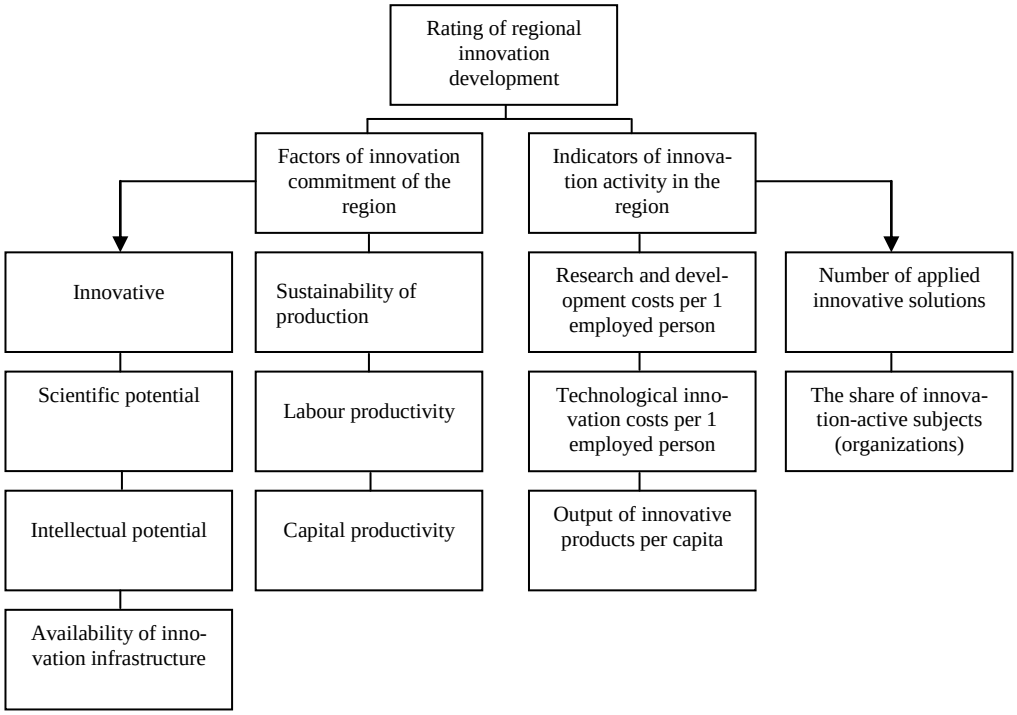

Fig. 2. *Rating factors and indicators of innovative development of the region*

An important factor in the effectiveness of innovation, in our opinion, should be considered the degree of innovation commitment, i.e. demand for innovation results in the economy and society. In modern science and practice, a single integrated approach to the innovation commitment to innovations in all spheres of society has not yet been formed [2,3,4], a model of open innovations requires national adaptation and updating [5,6].

When building a model, on the basis of the concepts of the main innovation systems and the necessary conditions for economic growth of the innovative type, we recommend four main levels: individual; organizational; integrated formations, including territorial clusters; and regional. It has been revealed that the degree of innovation impact on their development is determined by the presence and condition of innovation infrastructure in the region, institutional and organizational conditions, innovation policy. In order to determine the level of innovation and efficiency of innovation organizations, research and production systems and regions, we propose an integral indicator of innovation activity in the region, which can be calculated by the formula:

$$IPa = \sum p_i c_i , \qquad (1)$$

where IPa – integral indicator of innovation activity; p_i – weight of the individual *i*-indicator of innovation activity; c_i – points depending on the change of the individual i-indicator of innovation activity.

The main indicators characterizing innovation activity are presented in Table 2.

Table 2. Key indicators of innovation activity in the region

Indicator	**Calculation formula**	**Designation**	**Min**	**Max**
1. Innovative capacity of industrial production (I_{cp})	$\mathbf{X_1=I_{cp}=C_{ti}/V_{io}}$, where $\mathbf{C_{ti}}$ – costs on technological innovations of enterprises; $\mathbf{V_{io}}$ – volume of industrial output	X_1	0	1
2. Share of costs for technological innovations in the cost of innovative products of industrial enterprises (S_{ti})	$\mathbf{X_2 = S_{TI} = C_{ti}/V_{IP}}$, where V_{IP} is the volume (evaluation) of innovative products of industrial enterprises	X_2	0	1
3. Share of innovative products in total industrial output (S_{ip})	$\mathbf{X_3} = S_{ip} = \mathbf{S_{ip}/S_{ti}}$	X_3	0	1
4. Innovative returns (R_i)	$\mathbf{X_4 = R_i = 1/ I_{cp}}$	X_4	0	1
5. Share of innovation-active enterprises (S_{ia})	$\mathbf{X_5 = S_{ia} = Q_{ia}/Q_t}$, where $\mathbf{S_{ia}}$ is the share of innovative active enterprises in the total number of the surveyed enterprises; $\mathbf{Q_{ia}}$ – quantity of innovation active enterprises; $\mathbf{Q_t}$ – total quantity of surveyed enterprises	X_5	0	1
6. Share of integrated formations of education, science and production systems	$\mathbf{X_6 = S_{if} = Q_{if}/Q_t}$, where $\mathbf{S_{if}}$ is the share of integration units in the total number of enterprises; $\mathbf{Q_{if}}$ – quantity of enterprises, organizations in integrated formations; $\mathbf{Q_t}$ – the total quantity of organizations and enterprises in the region	X_6	0	1

To calculate the innovation activity it is necessary to trace the nature of changes in the calculated indicators of innovation activity ("+»/"-") and, depending on it, to assign to each indicator the corresponding point (Table 2).

Taking into account the obtained points, we calculate the final integral indicator of the innovative activity of the region according to the basic formula:

$$I_a=X_{11}C_{11}+X_{12}C_{12}+X_{13}C_{13}+X_{21}C_{21}\ldots\ldots X_{61}C_{61}+X_{62}C_{62}+X_{63}C_{63}. \quad (2)$$

Depending on the obtained value of the final indicator, it is advisable to determine the level of innovation activity of the region through the following criteria:

– the value of the integral indicator of innovation activity varies from 3 to 2.5 – the region has a high level of innovation activity;

– from 2.4 to 2 – the region has an average level of innovation activity;

– from 1.9 to 1 – the region has a low level of innovation activity;

– from 0.9 to 0 – the region has a low level of innovation activity and is unattractive for potential investors.

Thus, the calculation of the integral indicator by the proposed method allows to identify weaknesses and strengths in achieving innovation activity in the region, taking into account the development or slowdown of integration processes in the fields of science, education and production.

Creating conditions for commitment to innovations in economic entities of the region provides a group of activities related to the legal and regulatory support of innovation, regulation of innovation policy, public awareness. The most important role belongs to the human factor, which has the main potential and at the same time – the main danger in creating innovation commitment of economic entities.

Conclusion

Limited opportunities, territorial and administrative isolation of the regions with a peripheral geographical location, including the Altai Territory, as well as other territories adjacent to Kazakhstan, do not allow a fast creation of a highly effective basis for innovative development in each individual territory. While a number of technologies that are of interest for business have been offered by science, business is financing development of only 15-20% of the technologies, and cannot participate in more than 60% of the innovation developments.

Modern innovative production makes it necessary to expand the integration of science, education and production not only in the economic but also in the territorial aspects. Integrated forms of science, education and production become the basis of innovative economic development, and their interaction goes beyond a single administrative unit, extending to the adjacent, cross-border territories. At the same time, the core of development is formed in the form of a cluster representing a localized innovation subsystem of cross-border regions. In this regard, development of theory, methodology and recommendations for the practice of spatial integration of science, education and production, formation of spatially localized innovation subsystems including cross-border areas on the basis of their innovative potential is an urgent problem that has not received due attention in the economic research yet.

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REGULARITY IN INNOVATION AND PLANNED AGING

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Abstract: *Technological development and its consequences, in the form of innovative aging of products and processes, lead to producers' attitude towards searching for ways and means of improving and changing their parameters. The trend of changing the parameters of innovative products and processes as a result of their rapid innovation aging has already formed a new alternative concept for innovation development. It also puts new requirements both on the consumer nature of innovative products and on the methods, approaches and ways of their production and consumption. The main directions that provide an effective way out of the constraints imposed by rapid innovation aging to create competitive innovative products are being actively applied by many companies in automotive and electronics. This new approach, quickly adopted by manufacturers, is already showing its advantages in the practice of many industrial companies. The purpose of this article is to explore this process and define the main directions of its alternative and development. In essence, this means shortening the life cycle of products and reducing their resource use.*
Keywords: INNOVATIVE DEVELOPMENT, INNOVATIVE AGING, PLANNED AGING, ETC.

1. Introduction

The trend of changing the parameters of innovative products and processes as a result of rapid innovation has begun to gain momentum. This speed is also in line with the aging plan for businesses or the fact that industrial products are becoming more and more damaged and increasingly need to buy new ones. It is usually acceptable for the products to arrive on the products within a few days after the expiry date. In addition, people also use some of the ways to catch up with aging, which has become the term "planned aging". They have many industrial products that are designed to compete with new ones as well as new products and services that use this market approach. There is also an alternative to innovative aging, which is actively applied by many companies, both in household and electronics, as well as in automotive and aviation engineering. This new, integrated, dynamic and alternative approach, which was quickly adopted by industrial companies, already shows its advantages in the following directions:

- New age is considered to be an integral part of every stage of our life. It is the main engine that drives science, technology and the economy forward.
- Planned aging as an established practice of modern industry has been deepening in recent years, shows a German study by the Federal Environmental Protection Agency. However, many experts, along with some of the manufacturers, believe that the frequent change of models leads to waste of resources and environmental damage. It appears that the average life of home appliances has decreased over the last few years by more than 3 years.
- The aim at the beginning of the last century was for industrial companies to produce better quality by keeping almost the same price. Or, the longer the life of the products is possible at the same price. This was the goal in the past, and today with the global economy and competition everyone wants to sell more and faster. This means that the repair stage of industrial products is already lost.
- Many experts believe that the shortened life of industrial products and equipment is achieved partly through the use of lower quality materials.
- Other experts believe that the planned aging by demonstrating its qualities of category efficiency should also be taken as an alternative to rapid innovation aging.
- Among the driving forces behind this process is the consumer-driven drive for industrialized products.
- High impact of environmental factors in the global environment.

The advantages of this new approach are shown in the following graph, Fig1.

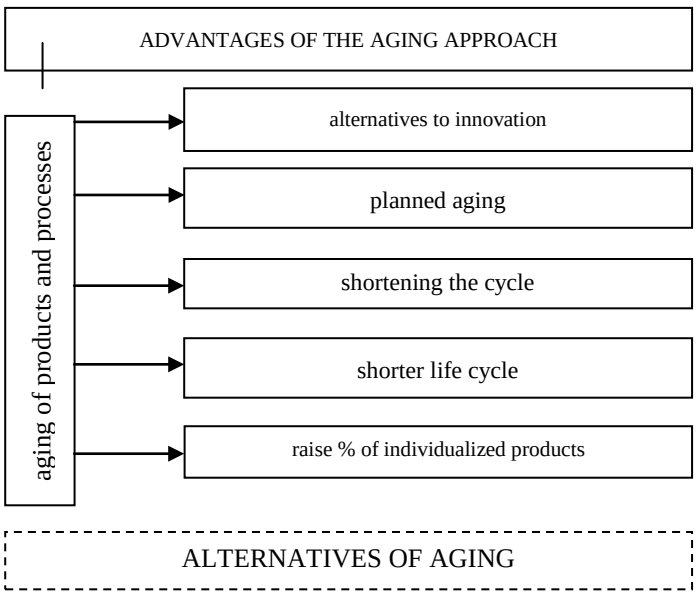

***Fig 1.** Advantages of the aging approach.*

2. Planned (regulated) aging.

Planned or regulated aging is an American initiative from the early 20th century. The phrase "planned obsolescence" became popular after 1954, when American industrial designer Brooks Stevens gave the following definition in a speech: "creating a desire for the user to have something newer, a little bit better than it is needed. "Since then, large companies have begun to invest in development projects to produce the" next best product ", including through design change itself. According to a German study submitted to the Bundestag in March 2013, the damage from such practices amounts to EUR 100 million per year.

As a result of several crises that are devastating to the global economy, real producers see that the problems of the global economy are rooted in the over-saturation of the market with commodities with too long a life cycle and difficult to improve consumer qualities, including design. It has to be concluded that the high quality of consumer goods inevitably leads to economic crisis, unemployment, and so on. An analysis has also been made that consumers are reluctant to spend a lot of money on quality equipment, but they are happy to make emotional purchases of low-quality, efficient design.

Currently, many manufacturers and consumers are opposed to the global approach to planned aging, but it is also certain that almost all of them work in a place that depends on the planned aging. Research, offices, factories, workshops, services - everything works because of the principles of planned aging. And this is not a temporary but a mandatory mechanism of the consumer society, driven by currency signs, circulation and replacement of products and services, which has already built its own principles of development and refinement.

3. Principles of planned aging.

Planned aging is based on the following basic principles;

- Deliberately planned lifecycle of the entire product (warranty period, expiration date, service life, etc.).
- Scheduled limitation of product properties for subsequent improvements (example of locking (freezing) some product functions ie it becomes non-functional.)
- Offering products with poor user qualities to be replaced by a better alternative (eg laptops and displays, or limited color coverage, poor spectrum, etc.)
- Mandatory introduction of legislative sanctions and obliging consumers and producers to update the product (eg, handsets, control devices, etc.)
- Expanding design and introducing one that is influenced by fashion marketing and seasonality factors;
- Suspend the supply of industrial products in exploitation with inexhaustible production resource (especially characteristic of computer equipment).
- Integration of components with lifecycle constraints, but including over 50% of the product value.
- Embedding of complex non-repairable items (capsulated). .Application of a single mailbox causes the device, device, etc. to be compromised, to meet the needs of the computer or to respond to any problems that may be caused by a crash, etc.
- Restrict the product's shelf life.
- Use of low-grade and low-grade materials, means that for every new device or product we buy, more consumables, more energy and more water are needed. And this leads to further pollution and greenhouse phenomena for the planet.

These principles of planning the aging of industrial products are shown in Figure 2.

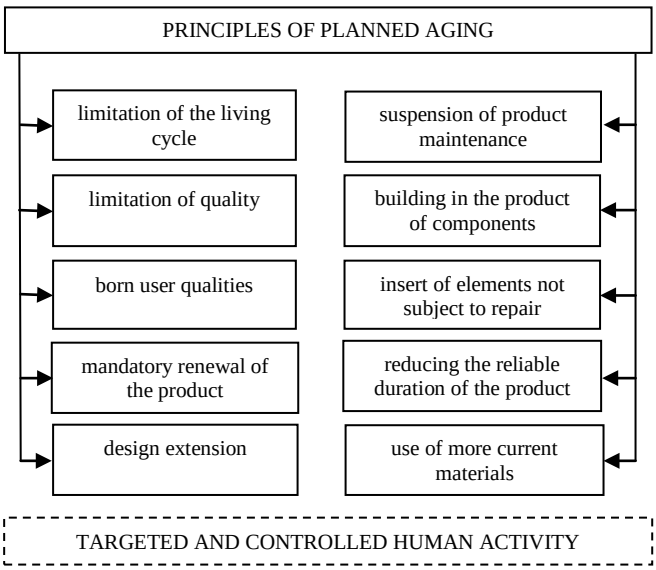

Fig.2. *Principles of planned aging*

As a conclusion to the above, it can be assumed that planned aging is purposeful and controlled activity by man in order to solve some industrial, economic and social problems of the development of society. Including satisfaction of user's individual requirements. Considered as a development, from this point of view and from this angle of view, the planned aging is increasingly becoming an alternative to the rapid innovation of product and process aging.

4. Innovative aging.

Innovative aging is an inevitable consequence of innovative developments in the field of technology and technology on a holy scale. This direction of innovation aging emerges under the influence of innovative solutions expressed in the new, more modern, more productive and improved techno-economic indicators, constructed and introduced in production, machines and equipment compared to those produced before them. In these cases, the efficiency of the use of old machinery and equipment will be significantly lower and will devalue themselves to a certain extent. The effect of using such a technique will be reduced as the magnitude of this decrease will depend on the power of the manifestation of the factors characterizing their innovative aging.
Innovative aging in its manifestations contains some features that most fully reveal its essence and the economic consequences of its influence on the elements of production. [11] The main feature is that it generates partial or complete relative devaluation of machinery, apparatus, equipment and other elements in terms of their user value, resulting in the need to replace the technically outdated equipment with a new one before it expires the duration of her physical wear. The economic feasibility of such substitution is not determined by the very fact of the emergence of new machines of similar technological purpose but by the degree of the innovation depreciation of the machines and equipment in operation and the level of lowering the technical and economic efficiency of their continued use. However, it should be borne in mind that the loss of consumer value and the need to replace machines is conditioned by a number of factors reflecting the specific directions of the impact of innovation development.

Taking into account these factors that characterize the qualitative side of innovation development, it is possible to reveal not only the mechanism of its impact on performance indicators but also its impact on the different aspects of the production process. Therefore, innovation aging is a legacy of innovation in all directions of world progress.

5. Principles of innovative aging.

The basic principles that provide an effective way out of the constraints imposed by rapid innovation aging in creating competitive innovative products are actively applied by many industrial firms. The basic principles of innovation aging rapidly adopted by industrial firms already show their advantages in the following directions:

- application of the modular principle of design and production of innovative products;
- Design and production of modules with different technological purpose;
- Design and production of innovative products with the highest possible reliability and short service life;
- Consideration of the design and production cycle as a continuous process and use of the methods of competitive engineering, simulation, virtual presentation, etc. with the aim of shortening the cycle as much as possible;
- as short a cycle as possible from an idea to an innovative product.

Innovative obsolescence is a regularity, and it imposes conditions that companies must comply with. This stems both from their technological attitude and from the strong impact of consumer interest on them. That is why more and more companies are starting to apply flexible technological and organizational forms of behavior

to the surrounding industrial and market world, which are an alternative to rapid innovation aging.

6. Technical progress and innovative and planned aging.

It is well known that technical progress, innovation development, innovation aging and planned aging are interconnected but they are not unique. They are not the same manifestation, although there is a definite relationship between them. This relationship essentially defines objective interactions and impacts on both world progress and the social relationships of society as a whole.

The interrelationship between innovation development, innovation aging and planned aging is shown graphically in Fig.3.

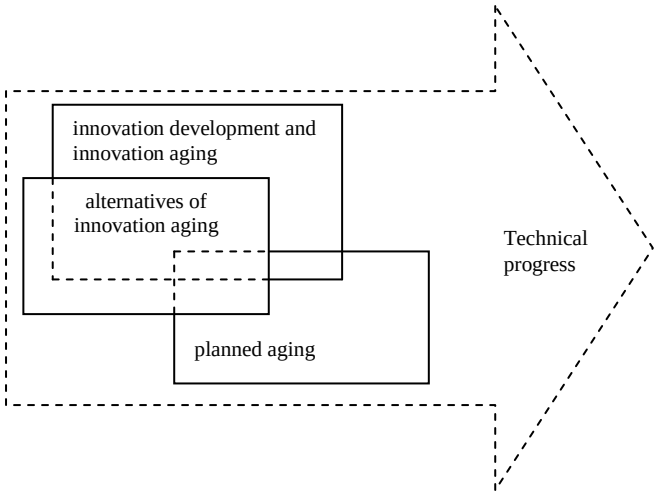

Fig.3. *The interrelationship between innovation development innovation aging and planned aging*

7. Imposed world practices and development trends.

Many companies that have captured elite and profitable corporate markets to be fair to the global economy also offer mediocre consumer technology, but are distinguished by its name and origin. Some models are positioned only for certain markets. There is also a big difference in the design and production of this technique. Typically, the elite series of large companies are produced in special factories. In addition, each user class has a planned aging and the mechanisms for achieving it are varied. Such aging mechanisms, the need for renewal, and even a defect in the technique to be profitable for maintenance only until the end of their warranty period are set. Such examples have many, but are most typical of computer technology. As examples, the following mechanisms already used in the art, including;

- Poor cooling, which is amortized and leads to a graphics card defect, recently and a processor (yes, many Intel Core processors have "died" unexpectedly). Designed to be non-preventive, difficult to replace, with a turbine that easily collects dust, with improperly installed ventilation openings that suck up rubbish;
- A battery with a limited life resource that has a chip that keeps it "alive" for about a year and subtle items. Chips with counters also have custom-grade printers;
- Built-in defect in a graphics chip, chipset, power supply, inverter or other important component. A striking example of this is the graphics card of Nvidia, later also of AMD / ATI;
- Slightly chassis, which leads to bending, cracks unmasking on a motherboard, display, hard drive and more. important components;
- A hard disk designed to last until the end of the warranty period. The new "magnetic" drives have a much shorter resource than the old ones for SSD enforcement;
- Stay or limitation of maintenance on older models are simulated traffic flows passing through various jobs The resulting results provide effective operation of the automatic workshop created to clean metvarhnini before painting.

In many of the technical universities in the world, the mechanisms of planned aging are studied by young engineers, designers and programmers. And that's okay because these specialists have to keep the world economy working and serve the interests of their investor. There is room for the idealists who want to design the perfect technique. Their task is to make quality corporate products for special purposes and special users. At present, the economies of individual countries, and more recently on a holy scale, are increasingly beginning to rely on planned aging, which is also beginning to control the development of technical progress. Revolutionary discoveries are bought, destroyed or stored for future use in the interest of planned aging. Small hardware and software companies with highly innovative new products are swallowed by the big ones in order to preserve the status quo and ensure a steady progressive development. There are many examples of the absorption and stopping of revolutionary technologies. It makes it imperative that you follow the principles of planned aging, and the bigger you are, the more aggressive you need to do in the development of the industry. This also imposes a planned success.

8. Constructive changes in products.

As a practice, there is already a requirement that a planned outgrowth technique is not intended for the consumer market, and the availability of this segment is not desirable for the global economy. Even if it is offered for sale outside of the corporate markets, its price is overwhelming for most consumers. Example: Hardware printers of the corporate market (eg Workstation) can be acquired by individuals after their use by a corporate client. This is an excellent opportunity at a low price to acquire a unique product without a built-in timer for aging and defect. Despite its high price on the consumer market, elite models are profitable for the corporate customer because they are bound by a quantity contract and subsequent replacement of the model with newer after 1-2 years. That's why sometimes a company that wants quality equipment for 100 jobs and it is more profitable to buy 100 computers with a corporate contract than the same 100 of the consumer market. Therefore, much of the computers and laptops offered were not in operation. Every retailer of used computers receives offers describing the parameters and the state of the art. Unlike other vendors who order middle and bad status due to the lower price, it is preferable only a technique with a high to perfect status.

In conclusion, it should be noted that the market is regulated not only by producers and intermediaries, but also by consumers. [12] As you can see, the market also offers products without planned aging, which are affordable or even in some cases lower than the products that are still defective. The spare parts which are necessary for the proper and safe operation of the products must be provided at a price commensurate with the nature and the life of the product.

9. Technological changes.

Investigation of physical and innovative aging in the context of solving contemporary development problems requires a review of traditional or conventional approaches to the formation of requirements in the use of technology and technology, and the search for flexible organizational forms of application. Given that the issue of creating new technologies, machines and devices essentially follows an upward trend of permanent innovative solutions leading to rapid innovation of technology and technology aging, the problem of planned aging is also developing. This development is in the direction of a regulated perception of the process of technical progress in the world.

The following conclusion can be drawn from this article. Analytically, the processes of innovation development, innovation aging and planned aging are analyzed. On this basis it is proved that there is a certain interdependence and interdependence between them. The more active the innovation development, the faster the innovation aging, this dependence can be assumed as a regularity. As far as planned aging is concerned, it is becoming more and more emerging as an emerging alternative process of innovative aging.

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ORGANIZATION OF THE MANAGEMENT SYSTEM FOR EFFICIENCY OF USE OF INVESTMENT POTENTIAL AT INDUSTRIAL ENTERPRISES

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Annotation. *The possibilities of using the investment potential of industrial enterprises are investigated. The expediency of formation of investment potential of industrial enterprises is substantiated. The methods and procedure for assessing the effectiveness of the investment potential of the enterprise are analyzed. The organization of the system for managing the efficiency of the investment potential of an industrial enterprise is proposed.*
KEYWORDS. *INVESTMENT POTENTIAL, METHODS, STAGES, ORDER, EFFICIENCY, DEVELOPMENT, PROJECT, MANAGEMENT SYSTEM, ANALYSIS, CHOICE.*

Analysis of recent researches and publications.

With the growth of investment at industrial enterprises, the production of new types of products, expansion of markets, the establishment of foreign economic relations, the attraction of advanced technologies the level of investment capacity and activity of the enterprise increases. The setting up of investment activity requires a thorough analysis of the risks of the investment market, the assessment of economic development, the determination of the environmental factors, the implementation of the forecast of the functioning of the market. The improving the level of development, strengthening the competitive position in the market, increasing financial stability, improving the economic situation in the country testifies to a high level of investment activity and improvement of investment activity. Planning, development, implementation, management and implementation of investment activity is carried out with the help of investment potential. The development and implementation of an investment project is a mechanism for identifying, growth and adoption of the investment potential of an enterprise, therefore the study of this issue is justified and relevant. We believe that the use of investment potential of industrial enterprises creates opportunities for: increasing profits; minimize costs; growth of company's welfare; settlement of investment activity; forecasting the size of financial investments; establishment of relations with the state; execution of contracts; assessment of investment risks; adjustment of production process and organizational structure.

Tolpezhnikov R.A., Mamatova L.Sh. [1, p. 360-361] proposed a model for assessing the financial and investment potential of the enterprise. The proposed model is carried out at the following stages: collection, processing and analysis of information on the activities of the enterprise; assessment of the existing level of financial and innovation potential, analysis of financial activity indicators; definition of normative values of financial and innovation potential; comparison of actual results with normative indicators; identification of additional funding sources; conducting an analysis of the effectiveness of the system of development of financial and investment potential; development and use of ways to increase the financial and investment potential of the enterprise. The mechanism of providing financial and investment potential, which is based on the stages of planning, organization, and control, was considered. However, the author did not take into account the stages of implementation and development of the investment project, did not reflect the impact of the threat of the investment market.

Pashkevych M. [2] adhered to the idea that the concept of investment potential and investment attractiveness are different. Therefore, the investment potential was considered as a process for the effective use of own, borrowed, debt resources, available opportunities in order to improve the economic development of the enterprise, betterment the environmental safety and social development. In addition, the efficiency of management of the investment potential of an enterprise is evaluated using: the coefficient of investment potential use; the level of used investment potential. Dorosh Yu.V. and Gulko L.G. observed the theoretical aspects, role, scheme of development of investment potential. [3, p. 289]. The scheme of development of investment potential takes into consideration the influence of factors of external and internal environment on the development of the enterprise's potential. In the given scheme the level of interaction of technological, innovative, economic, informational, organizational, competitive, labor potential with the development of innovative potential is determined. It can be argued that in order to establish investment potential, to improve investment activity, it is necessary to take into account development opportunities, financial resources, and the influence of exogenous and endogenous factors.

The classification of the factors that influence the formation, development and efficiency of the investment potential of the enterprise was proposed by Bormotova M.V., Moskalenko B. A., Sukhorebryi Y.V. [4, p. 60-62]. These factors were divided into two groups: by sources of origin - external and internal factors; by direction of influence there are the mobilization and application of investment resources. Internal factors include: financial and human resources; supply of raw stuff and materials; demand of buyers; position of the enterprise in the domestic market; level of competition; support from the state. The factors of external influencing are: inflation; exchange rate fluctuations; trust of investors; tax regulation; development of the country's economy; the level of corruption. We believe that the level of influence of these factors must be taken into account in the formation and development of investment potential, so far as the assessment of factors of the market environment allows to identify threats, risks, and to establish financial sustainability of the enterprise.

Results.

The process of organization of management begins with the definition of purpose, the formation of goals and objectives without which the investment project is impractical and there are no reasons for its implementation. The targets and objectives of the investment project must be in line with the interests of the enterprise. The following is an analysis of the results of the financial activity of the company in order to conclude new contracts and obtain loans. Methods play an important role in the process of project management, since they are used to assess the risks and threats of the environment, determine the project's duration, main goals, targets and objectives, form a project team, calculate the amount of borrowed funds, determine the sum of required financial resources, estimate costs, form the budget of the project, monitor and evaluate the effectiveness of the project, make management decisions, enter into contracts with suppliers. Consequently, the process of organizing a project management system depends on the rational use of management methods.

In general, there are different approaches to construction a management system for investment projects that have advantages and disadvantages, but the proposed system is efficient and profitable, so far as the relationship between the enterprise and the project team is taken into account, the threats and risks are considered, the factors of the internal and external environment are assessed, the financial condition of industrial enterprise is estimated, algorithm of action, operation of the project team is defined.

In difficult conditions of development in Ukraine there is a decline in economic activity of industrial enterprises due to the instability of the economic situation. An important prerequisite for establishing economic development, increasing the competitiveness

of industrial enterprises in the international market, improving social development and welfare of the population, filling the state and local budgets, and successful development of the region is attraction of investments. However, Ukraine is characterized by the ineffectiveness of passed legislative acts, political instability, lack of state financing of industrial enterprises, aggravation of the socio-economic crisis, exchange rate fluctuations, high inflation and interest on bank loans, all that limits the volume of foreign capital investment in the activities of industrial enterprises. Most industrial enterprises are characterized by low level of financial stability, security of economic development, paying capacity, business activity, they lose competitive positions in the market and are unprofitable.

The only way to establish the development of industrial enterprises is to implement structural transformations both in the country's economy and in the growth of industries. In particular, at a state level, it is necessary to organize a well-balanced and well-founded investment policy that will facilitate investment attraction, their efficient allocation and use to satisfy state, regional and local needs, and implement development programs. The attraction of foreign capital is carried out in conditions of stability, reliability, development, and therefore this process will allow making structural changes in the economy of the country, improving social development, raising the security of development and the level of financial stability of industrial enterprises, and increasing the level of public confidence. In order to increase the country's economic effect from the use of investment capital, it is necessary to develop and implement investment projects of industrial enterprises, guaranteeing the rationality of using investment resources, protecting the interests of investors and maximizing achievement of the set goals.

For most industrial enterprises there is not enough own financial resources in the process of activity, therefore there is a need to attract either borrowed resources or investment capital. The use of borrowed resources will result in an increase in the amount of debt capital, accounts payable, which will cause a reduction in net profit, equity and, in some cases, will contribute to an increase in the volumes of production and sales. However, more rational for enterprises is investment attraction and participation in an investment project that will expand and change the structure of production, increase product range, modernize outdated equipment, carry out technical re-equipment, develop new types of activities.

Implementation of the investment project of an industrial enterprise will create preconditions for improving the welfare of the population, establishing socio-cultural development, increasing demand for products, filling the local budget, solving environmental problems, betterment of the medical care of employees, infrastructure growth.

In the process of developing an investment project, investors' interests and requirements need to be taken into account, as investors invest their financial resources, mainly in the short run, due to the desire to return the invested funds with interest. Investments in investment projects require a rather long period and is accompanied by a risk of non-repayment of funds. Therefore, investors, in order to assess the reliability of the investment project, analyze the following information: risks and threats of the project; provision with labor and financial resources; project cost; term of project implementation; goals and objectives; project business plan; comparison of several projects; enterprise activity analysis; choice of priority directions of investment of funds.

Kalinichenko Z. D. analyzed theoretical approaches to the interpretation of the essence of the concept of "investment potential of the enterprise", the characteristic features, functions and methodical approaches to the assessment of the investment potential. [5, p. 275; 6]. Methods for evaluation the investment potential, which are shown in Fig. 1 are used by industrial enterprises to calculate the cash flows, time for receiving revenue and paying off defrayal, project life and return on investment with interest payments, increase in revenues from participation in an investment project, assess investment risks, and make risks and threats predictable.

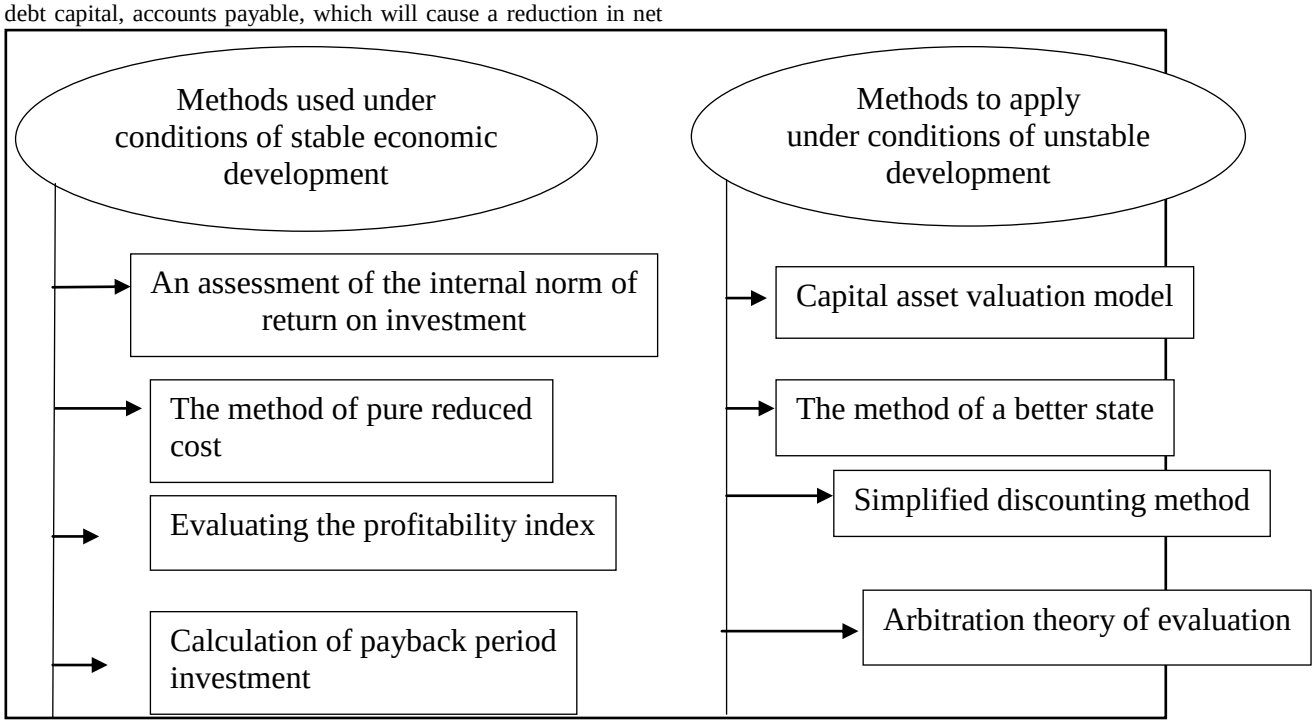

***Fig. 1** Methods for assessing the effectiveness of the investment potential of the enterprise [5, p. 275; 6, p. 213-214]*

In our opinion, the use of these methods will create opportunities for determining the appropriateness of investing capital investment, participation in an investment project, the formation of investment potential.

The order of estimation of efficiency of investment potential of the enterprise was proposed by Andrianov Yu.O. [7, p. 43-46], who argues that due to the investment potential, the company is able to increase its competitiveness, attract investment capital, expand its sales markets and manage its risks. The stages of assessing the effectiveness of investment potential include: collecting information and defining methods for assessing investment potential, financial sustainability, as well as the definition of normative values of indicators; there is a grouping of indicators by features or purpose; choice of coefficients for investment potential assessment; calculation of indicators; estimation of investment potential level. The advantage of this approach is the ability to assess the low,

medium, high investment potential of the company and develop measures to increase it.

Conclusions.

In our opinion, the mechanism for ensuring the development of the investment potential of an industrial enterprise is a complex organizational process that is carried out by implementing principles, methods, observance of functions, model, established norms taking into account the optimal ratio of own and attracted investments, time parameters, investment risk, which ensures the establishment of investment activity, level of activity, achievement of the established tasks with the purpose of improvement of development of investment potential as a mechanism component of the investment project and it secures the establishment of the enterprise activity and the development of the components of the potential in the long run.

The mechanism of ensuring the development of the investment potential of an industrial enterprise, in contrast to the existing ones, is a complex organizational process for improving the development of investment potential as an integral part of an investment project, for establishing enterprise activity and developing the constituent of potential in the long run through the implementation of principles, methods, observance of functions, taking into consideration available investment capital, investment risk, which creates an opportunity to resolve the investment problem of attracting investment resources, providing organization, forming investment potential.

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CRM SYSTEMS – FROM THEORY TO PRACTICE

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Abstract: *CRM Systems (Customer Relationship Management) - Customer Relationship Management Systems. The success of any company is determined by customers, their satisfaction with the company's products, their satisfaction with access to them and their willingness to return to the company. That's why every company has to give its customers the appropriate attention and time. However, this can be very difficult in practice.*

In fact, customer relationship management often involves lengthy searches for appointment notes, important customer information, and relevant documents. Therefore, this is an inefficient, costly and, in many, unnecessary way of working.

There are software solutions that not only save companies a lot of time, but also help them improve and streamline their customer communications. These solutions are referred to as CRM (Customer Relationship Management) - customer relationship management systems or otherwise customer systems. These systems are no longer hot news anymore, but they have recently gained enormous interest from both users and suppliers. To put it simply, more and more businesses have already recognized that keeping a customer is cheaper than looking for new ones that are not yet disappointed. At the same time, more and more software vendors have noticed that their customers are increasingly taking care of marketing and looking for the right tools for it.

At present, companies are increasingly focused on building, developing and effectively managing their relationships with their customers. One of the reasons for the increased focus on quality customer satisfaction was the change in the competitive environment in the 1990s and the impact of information technology development. The advent of the Internet has been strengthened by the ubiquity of competition.

One of the most effective ways a business can differentiate itself from a competition is a perfect understanding of individual customers and their needs, a personal approach and an excellent level of service. However, if a company has hundreds, thousands or millions of customers, it is impossible under normal conditions to know each other's wishes, needs and preferences. And that is why CRM systems have been developed that, when properly applied, enable a large number of individual customers to understand, tailor their offerings to their needs and wishes, and know and manage their value for society. In summary, simply automating business processes, such as logistics or human resource management, comes with the automation of customer contact.

Keywords: CUSTOMER RELATIONSHIP MANAGEMENT (CRM), CRM PROCESSES,

1. Short view to the past

At the end of the 1960s, some Ted Lewitt (business expert) declared that the basic principle of successful business is the ability to win and retain a customer. He said that a modern business should understand the whole business process as a firm commitment to discovering, creating, encouraging and satisfying customer needs. Lewitt had predicted the key roles of today's CRM systems by 30 years.

Thanks to modern technologies and possibilities of the Internet there is a significant increase in competition - even big suppliers have to worry about small competitors. Without Interne, small competitors would not usually exceed the region's borders. The Internet allows them to reach at relatively low cost customers around the world. In the recent past and today it is possible to trace 4 basic types of CRM systems, differing in the use of computer technology, the degree of automation of activities, the suitability of use for different types and sizes of organizations, and the extent and complexity of:

a) Paper database system

This is the oldest way to keep track of all customer-related activities. It has two great advantages - it does not depend on the use of computer technology and allows easy storage of documents that exist only in paper non-electronic form. It is a system in pure form of individual processes. The biggest drawback is the zero rate of activity automation - endless data copying, yearly database search, manual statistics creation ...

This system was justified when computing was too expensive for every worker to have a computer. Even now, with a well-functioning system of this type, we can meet most of the doctors - the patient card is a perfect record of our health history.

b) a Microsoft office packed solution

Such a system allows partial automation of some processes and activities. Once you have created an electronic contact database, you can easily automate the filling of templates, forms and tables, or set automatic alerts for important dates. However, the system does not offer the user any document management, analytical and statistical processes, or automation of reporting for colleagues and superiors. It is up to each user to create a system for storing documents or to perform statistical calculations and analysis using a spreadsheet editor. The most common used are Outlook, Excel, Word, Access ...

In the case of Outlook, this ambition is to form a system-wide integration article. Basically, it is an electronic filing system that can search and sort contacts in the database and support the automation of electronic communications. On the other hand, sorting and searching functions are limited. The main drawback is the linkage of all activities undertaken with the user, rather than being linked to the individual contacts in the database to which the activities relate. The basic advantage is low cost (programs are now installed on most computers) and automate the most repetitive data filling procedures. A significant advantage is the freedom to organize other necessary processes at their own discretion. Even this system is in most cases combined with the above-mentioned well-known file containing customer cards. Indeed, even the paper diary is not a lot of people willing to leave [1].

c) Programs for contact management and time management

These applications have pioneered truly electronic CRM systems. Even for users who are not 100% of their PCs, they are also comfortable in managing contacts, related documents and schedules. I can perfectly automate not only the processes of filling out documents, but also storing them in history (electronic customer card).

The database is built in such a way that not only contact information is stored in it, but also important business information - the size of the company, demand products, purchase volume, etc. The database can be used to search quickly and efficiently for the necessary criteria. The system is not built as a stand-alone application, but it uses broad links to other programs. In particular, contact management and time management systems are a well-developed database linked to the surrounding software world and

thus a unifying element that links individual "Office" applications to a functional whole. Although these systems are not the technological highlights of CRM, they are easy to use and maintain. For small and medium-sized organizations, they are currently the optimal solution to ensure customer care activities.

d) Complete CMR-systems

Nowadays, in the field of CRM, the technological top is made up of extensive electronic systems including 4 basic CRM modules:

- Automation of sales activities
- Marketing activities automation
- Automation of service activities and customer support
- E-commerce

These systems are mainly applied in large and multinational organizations. While previous contact management and time management programs can be considered a good sales activity automation module, extensive systems offer far more options. Very important is the interconnection of individual modules, which enables efficient communication and cooperation both in the horizontal direction and in the vertical direction.

They allow to analyze the customer's affection to purchase. From the CRM point of view, it is primarily the search for patterns and trends in customer behavior. Another valued analytical tool is monitoring customer value and managing it - it is about gaining the profitability of individual customers from available information and estimating their future potential [2]. The main drawbacks are the high purchase price, the need to ensure well trained users and the continued maintenance of the system.

1.1 The usual building of a complex CRM system

Most people with a basic awareness of CRM systems have in mind the automation of marketing and sales processes when describing them. They don't realize that CRM involves far more. In addition, the CRM issue cannot be reduced to software. It is only a support that facilitates and streamlines the functioning of the entire system.

In a basic and simplified form, CRM can be defined as integrating and coordinating marketing, sales and customer service into a unified and comprehensive approach to each customer's care. It technically includes the possibility to use all available communication channels, knowledge bases or web portals.

CRM can be divided into already mentioned 4 modules:

- Sales Activity Automation - Sales Force Automation (SFA)
- Marketing Activities Automation - Marketing Automation (MA)
- Service and Customer Support Automation - Field Service Automation (FSA)
- E-commerce - E-business (EB)

1.2 Automation of sales activities

It is perceived as the cornerstone of CRM. The module should allow all traders, possibly external business partners, quick and efficient access to important customer information, work program planning and use of knowledge bases and other sales tools included in the system.

- Main Module Features:
- Contact and Time Management
- Managing New, Unidentified Contacts (Lead Management)
- Management Reporting Tools
- Remote System Access Tools
- Business Partners Management

1.3 Automation of marketing activities

The marketing activities module is the heart of CRM. He plays a key role in creating strategies and tactics for long-term successful customer care. Creators and users of CRM systems are becoming more and more aware of the importance of this module, and will soon take over the dominant role that Automation of Sales Activities has advocated so far. The main function of the module is the Campaign Management.

This includes:

- Sorting database customers into groups and managing individual campaigns for individual groups
- All available forms of communication with customers: e-mail, Internet, phone, or print media
- Evaluation of the campaign conducted by sophisticated procedures, which are also a standard part of the module
- Mutual link between marketing and sales module

1.4 Automation of service activities and customer support

The task of the module is to streamline communication with customers and manage service activities after sale. The basic features are:

- Customer Center - communication by phone and Internet
- Field Service

1.5 Electronic trading

It is the youngest module experiencing a strong boom. In most cases, this is a standalone application on an Internet browser access base. It enables automated execution of business in electronic form. It is important to ensure maximum connectivity with other CRM system modules.

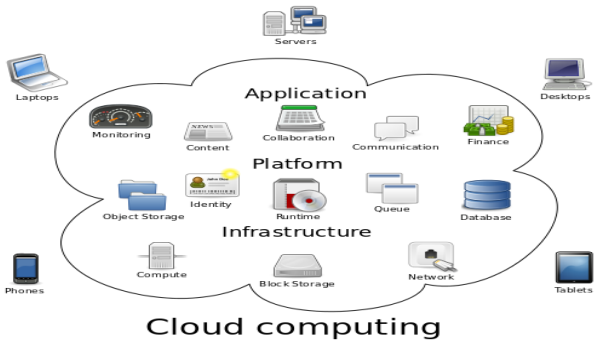

Fig. 1 Cloud computing

2. Development trends of CRM systems

The worldwide CRM systems market now has the following features:

Significant growth of the entire sector launched towards the end of the 1990s - growth in 2000 reached 38% worldwide CRM systems have become a global issue - the European and Asian markets show higher growth rates than the American market on which these systems have been pushed forward CRM systems are indispensable to most business sectors, being deployed not only in traditional financial services, telecommunications, or high technology industries, but also in industries including conservative defense industries

The global size of the CRM systems market is currently estimated by experts to be more than $ 12 billion. USD. In some countries (Europe), the growing use of CRM systems is hampered by strict legislation limiting work with personal data

Accordingly, I can therefore state the following:

- High growth of CRM systems market despite cooling of information technology industry
- The most important trend is the rapid development of Internet-based CRM applications
- CRM systems as a paid service
- Maximum openness of systems with the ability to run with important applications
- Higher modularity of systems - Add-on modules can be added to the module providing basic functionality

3. How to avoid the failure of installing CRM systems?

Part of the installation of CRM systems is their failure. Therefore, it is necessary to consider the causes of this frequent phenomenon. On a closer look at the situation, it is possible to recognize the shortcomings on the part of the supplier organization as well as the company itself.

The major shortcomings on the supply side include:

- Small vendor experience with a variety of industries. Not only every industry, but every company requires a CRM system tailored to its structure and internal processes.
- Promising too short implementation time and then impetuous deployment without sufficient analytical preparation
- Insufficient training of future system users and their motivation to change thinking and use the benefits offered by the system
- Insufficient advice after installation

On the contrary, problems arising on the part of the sponsor include:

- A biased image of the possibilities and real benefits of the system
- Pressure for rapid implementation regardless of complexity and persistence of people's thinking
- Selling insufficient documents on company processes and information flows to the supplier
- Low level of employee motivation to move to a new customer care system
- Lack of trust between management and employees

Once the implementation bottlenecks are identified, the business needs to follow this procedure so that the errors mentioned above do not happen:

Focusing on internal corporate processes and information flows: every effort should start here. It certainly pays not to rush and to carry out a thorough analysis of all company processes with an emphasis on those that are directly related to customer communications [3]. It will greatly help if a flowchart process map is created for each company department. Thus, the process links between the various parts of the company are well visible and often the internal processes are optimized and streamlined [4].

Choosing an Information System Configuration: There are a number of different systems available in a variety of configurations. When choosing, it is necessary to take into account the transferred process analyzes, business department, organization size, anticipated necessary costs, or future needs.

Fine-tuning the structure of the information system and its linking with other systems used in the company: the adjustment is carried out in cooperation with the system manufacturer, eventually. its supplier to ensure the smooth running of customer care processes and information flows. It should start from comparing automated systems processes with those identified in previous analyzes and identifying areas where the system needs to be harmonized with business needs.

Gradual implementation of the system: It is good to divide the implementation, especially for complex systems used in large companies and intervening in all organizational units. Beginning with the sales department and sales activity automation module, continue with marketing and analytics tools, and then eventually engage service, logistics, and other modules [5]. A necessary part of the gradual introduction of the system is the training of the staff connected with the motivation of the company employees to use the system.

Ensuring Feedback for Implementation Process Control: Continuous control must interweave the entire process from analysis to completion. Valuable control requires the use of measurement methods to quantify parameters. Above all, two basic parameters - the rate of return on investment and the level of relationship marketing achieved - should be subject to control. It is clear in practice that adhering to such a structured process of deploying a CRM system can significantly minimize the risk of failure.

The worldwide CRM systems market now has the following features: Significant growth of the entire sector launched towards the end of the 1990s - growth in 2000 reached 38% worldwide CRM systems have become a global issue - the European and Asian markets show higher growth rates than the American market on which these systems have been pushed forward CRM systems are indispensable to most business sectors, being deployed not only in traditional financial services, telecommunications, or high technology industries, but also in industries including conservative defense industries [6].

4. Conclusion

Customer Reletionship Management (CRM) has recently been heavily employed not only by software developers, solution vendors, but also by customers themselves. It can be said to be a fashionable hit in recent years. What is the development trend of CRM?

The approach has changed, from the original focus on productivity and profitability to focus on customer value. A genuine competitive advantage is no longer achieved through profits from operational efficiency or through product benefits, but through greater customer knowledge. The paradox is that in the past many CRM systems have, by their conceptual focus, actually diverted their attention from the increased focus on the customer and considered it to be a product. Operational CRM systems were used for customer care through product campaigns and call centers.

CRM has become a hit because it has promised to increase business turnover through campaigns to attract new customers and keep old customers on the one hand and save costs through productivity gains on the other. The main trend now is to focus on a rapid and measurable return on investment with respect to the final profit, as many past promises have never been realized. One consequence is the increasing trend towards analytical CRM. Directing has changed from increasing automation and commoditization to intelligence and uniqueness.

We can best illustrate the difference in these two approaches through a call center example where we can choose either Operational CRM to increase the number of calls a trader can make per day or analytical CRM to increase the number of calls made. We can say that we need both, but as the market is increasingly sensitive to the costs that both approaches require, it is a current

trend to choose one, based on parameters such as the need to improve customer dialogue, product production time and cost.

The strength of the Central and Eastern European region lies in the willingness to adapt to the speed of the market and to accept the historical data acquired by individual firms about their customers. However, these historical data are often stored in old systems, which in turn requires a broad portfolio of options to access them. However, such data is clearly a competitive advantage for the local organization, as opposed to global or local competition, which is unable to benefit from this advantage. The biggest challenge in any project is to consolidate all customer data while maintaining the consistency and quality of the data [7]. Many projects have not been successful in the past, as new customer data warehouses have begun to be deployed and all historical data stored in old OLTP systems has simply been ignored.

5. Acknowledgement

We cooperate with VIPO, a.s. In the near future, we plan to contribute by introducing a new CRM system to achieve better insight into customer needs and requirements, timely handling of claims and more comfortable collaboration and customer care to achieve higher profits.

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BUILDING AN INTERPRETIVE STRUCTURAL MODEL FOR FACTORS DEFINING CO-PARTICIPATION LEVEL IN AN INDUSTRY 4.0 ENVIRONMENT

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Abstract: *This publication addresses the factors that support the process of developing an individual approach to customers, which is one of the main tasks of the so-called Fourth Industrial Revolution or Industry 4.0. The emphasis is on the study of the interrelationships and the interaction between these factors and their integration in a structured way, with the help of the so-called Interpretive Structural Modeling (ISM) to help integrate them into a comprehensive conceptual framework that represents producer-customer interactions under Industry 4.0 conditions and, as a result, increase the efficiency of the process of creating value according to the individual requirements and expectations of the customer.*

KEYWORDS*: ISM, INDIVIDUAL APPROACH TO CUSTOMERS, INDUSTRY 4.0, SUPPORTING FACTORS, CO-PARTICIPATION, DIGRAPH, INTERRELATIONSHIP*

1. Introduction

Individual approach to the customer finds its way even in the time before the first industrial revolution, when there also have been a number of customized/individual products or so-called One-of-a-Kind Products. This has not been causing a serious disturbance for manufacturers due to the significantly limited scale of the activity, geographically isolated markets and insignificant competition.

However, with the growing industrialization, the scale of manufacturing has been gradually expanding, the number of customers grew incredibly, and the satisfaction of their individual requirements and expectations become impossible. In an effort to meet the demand, manufacturers rely on standardization and uniformity of production and take advantage of the opportunity to realize economies of scale.

In the late 1960s and early 1970s, however, the tendency to individualize (customize) the production, but on a much wider scale than the old ones, began to imply, until it came to its full manifestation today.

Given that almost all products nowadays have alternative substitutes and market supply significantly exceeds market demand, it is becoming more and more difficult to satisfy the preferences of customers who are constantly changing and growing in quantity. Every one of them expect to receive a unique product as well as one-to-one marketing. The "typical" customer no longer exists. Given this, the achievement of the corresponding degree of product capitalization, which corresponds to the expectations of the clients, becomes an increasingly difficult task for the producers.

Various approaches are considered in the literature to help producers perform an efficient customized production through customer engagement in the process of creating and manufacturing the product, such as Customer Order Decoupling Point / CODP, Mass Customization, Co-Production, Order Penetration Point, Point of Postponement, etc.

The technological potential of Industry 4.0 makes operations system of the enterprise more efficient in adjusting to the individual and specific requirements of each individual customer in terms of design (the physical structure) and functional features (functional structure) of the end item (the final product) [1,2,3,4,5,6]. Thanks to Industry 4.0, even manufacturing of individual components (batch of one component) can be profitable [2,5,7,8,9]

The purpose of this publication is to investigate the interrelationships and interactions between the factors that underpin the process of product customization according to the expectations of each individual customer. Building a model describing the connections and interaction between these factors will help to integrate them into a comprehensive conceptual framework, presenting the *producer-customer* interaction in the conditions of Industry 4.0 and, as a result, will lead to an increase in the efficiency of the process of creating value tailored to the individual requirements and expectations of the customer.

2. Building an Interpretive Structural Model for Factors Defining Co-Participation Level

To investigate and structure the interrelationships and the interaction between the factors that determine the level of customer involvement in the value creation process, the use of the so-called Interpretive Structural Modeling (ISM) hereby is proposed. ISM was created by J. N. Worfiled as a computer-added methodology to study complex issues and to structure them in terms of words and directed graphs which can be easily understood [10].

2.1. Interpretive Structural Modeling Methodology

The ISM application is based on the methodological order presented below [10,11,12,13,14] .

Step 1: Problem Identification

One of the main areas in which Industry 4.0 enables improving operations is the achievement of an efficient product customization, considering individual and customer-specific requirements in the value creation process. With the help of the Cyber-physical systems (CPS), Internet of Things (IoT), Internet of Services (IoS) etc., Industry 4.0 allows for a major change in the way of implementing and managing a customer-to-customer interaction [1,2,5,7]. Thanks to them, it the so-called "Smart Factory" is possible to build, in which physical processes are performed and monitored by CPS maintaining a digital duplicate of the entire operations system and, correspondingly – of the processes performed by it, taking decentralized decisions. Through IoT, CPS interact with each other and with people in real time, and this makes the operations system more adaptable, efficient, and more customer-oriented, e.g. – agile.

To achieve a high degree of operations system responsiveness and comprehensive flexibility, a great degree of contribution is brought by the new capabilities of 3D-printing (Additive Manufacturing). Based on CAD data, components of metal, ply or ceramics are produced that up to now would be very difficult manufactured or with high cost. This method allows small-volume and less-weight manufacturing, as well as achieving higher product strength and reliability. Another very important advantage of 3D-printing is the ability to react quickly when changing product structure and design.

To summarize, technological change can provide a more flexible way to serve the customer's individual needs through a comprehensive digitalization of the operations system performance. This way, with the help of ISM, it is necessary to establish the dependencies between the factors influencing the customer's degree of co-operation in the value creation process and their presentation in a structured manner so as to assist their integrating into one complete digital model for an effective customization.

Step 2: Identification of the Factors

Based on a deeper analysis of the literature [15,16,17,18, 19,20,21,22,23] factors, defining the opportunities for customers' co-participation could be classified in three main groups:

(F_1) Factors, characterizing Market Demand

- *Customer Attitude* ($f_{1.1}$) – this factor is related to the customer's expectations regarding the delivery time for the item ordered (product or service). Two scenarios are mainly discussed [25,26]: (1) "*Immediate purchase*" – limited customer intervention is presumed and (2) "*Ready-to-wait*" – most often the customer's attitude for waiting is connected with his/her requirements to the end item in terms of brand, quality etc. The more specific these requirements are, the higher the degree of customer's intervention in the process of value creating.

- *End Item Price* ($f_{1.2}$) – it a complex economic category in which the interests of both the producers and the customers reflect. When the focus of producer's attention is on proving a competitive price, the tendency is to reduce the degree of customization. On the other hand, when the aim is to meet the specific requirements of the customers, then the higher the price is acceptable and the tendency is to increase the degree of customer engagement (it could vary from "Distribution-to-order" to "Design-to-order").

- *Type of Market Demand* ($f_{1.3}$) – three situations are considered to have an impact on the degree of customer engagement: *(1) Independent Demand, (2) Dependent Demand, and (3) a Combination of Dependent & Independent Demand.* In the first case, the customer's role is depersonalized – he/she don't participate in the end item forming. In the second case, the end item is formed entirely by his/her specific preferences – in terms of raw materials, the manufacturing technology, product design etc. As to the third case, it implies an intermediate degree of customer engagement, which sometimes means sub-assembly to order of some of the components, or assembly to order of the end item.

- *Demand Volume* ($f_{1.4}$) – (1) Large-volume, (2) Medium-volume and (3) Low-volume market demand. In order to be adequate to the current market situation, the producers should focus on the search for opportunities, regardless of the volume of demand, to ensure such a degree of customer involvement that meets their requirements. This is one of the most serious challenges facing modern businesses, which Industry 4.0 promises to overcome.

- *Demand variability* ($f_{1.5}$) – the following types of market demand nature exist: *(1) uniform, (2) variable and (3) seasonal/ cyclical*. In all three cases, the aim is to ensure the greatest possible involvement of the customer for the particular situation, up to the degree to which it is profitable for the enterprise. However, this consideration is true of any of the factors relevant to the problem discussed.

(F_2) Factors, Characterizing the Product

- *Product Architecture* ($f_{2.1}$) – this is one of the factors with the most important significance, as far as the opportunities for the product variance are considered, therefore it is a basic indicator for the product complexity. Given the architecture specificity of the product, the company must be very cautious in determining the point (operation) up to which the customer should be "allowed to penetrate" the process of end item determining, because in some cases this may lead to deterioration of product qualitative and functional characteristics. The aim is to design/construct products with a high degree of architecture *modularity*, as it is an opportunity to "control" the diversity and to some extent makes the task of the manufacturers easier. In addition, as far as the degree of customer involvement is concerned, it has the potential to vary from "make-to-order" up to "sub-assembly/assembly on order". Also, the more modular structure of the final product, the greater the possibilities for product customization, which enables a higher degree of customer involvement (up to "design-to-order"). Otherwise, a good strategy would be to allow the customer to penetrate up to "sub-assembly/assembly on order".

-

(F_3) Factors, characterizing Operations Processes

- *Delivery Time* ($f_{3.1}$) – the time period between the moment of receiving the order and the moment of delivery of the product to the customer.

- *Process Flexibility/Agility* ($f_{3.2}$) – the higher the degree of flexibility and dynamism of the production process, the greater the possibilities for a higher degree of customer involvement.

- *Process Modularity* ($f_{3.3}$) – one of the main prerequisites for assisting the producers' pursuit of product customization [27,28,29,30]. In fact, through modularity, some degree of unification of the manufacturing processes for the various components and/or end items from the product mix of the enterprise. This reduces the variety of operations and/or processes that could potentially be affected by a customer's intervention, which in turn favors their effective organization and management.

The factors discussed so far could be combined in a single model with the help of ISM to present the interrelationships and interactions between them and to take into account their complex influence in deciding on the level of customer involvement in the value creation process. They will be grouped as follows:

Step 3: Defining the Relationships between the Factors

According to the ISM methodology, it is necessary to define the dependencies between the observed factors. Table 1 lists all possible dependencies that may occur among the factors presented in step 2. The table also shows the assumed conditional indications of the individual dependencies to be used in the following steps:

Table 1. Relationships between any two factors (*i* and *j*)

F:	Forward relationship from factor f_i to factor f_j i.e. factor f_i helps to achieve or influences factor f_j;
R:	Reverse relationship from factor f_i to factor f_j i.e. factor f_j helps to achieve or influences factor f_i;
FR:	Dual directional relationship i.e. factor f_i and factor f_j helps to achieve or influences each other;
X:	No relationship exist between factor f_i and factor f_j.

Step 4: Developing Structural Self-Interaction Matrix

In this step, the so-called Structural Self-Interaction Matrix (SSIM) is developed, in which the dependences between each two factors are expertly defined. The SSIM case presented in this publication is shown in Figure 1.

X axis / Y axis		F_1					F_2	F_3		
		$f_{1.1}$	$f_{1.2}$	$f_{1.3}$	$f_{1.4}$	$f_{1.5}$	$f_{2.1}$	$f_{3.1}$	$f_{3.2}$	$f_{3.3}$
F_1	$f_{1.1}$		F	R	R	R	R	FR	FR	FR
	$f_{1.2}$			R	FR	X	R	R	R	R
	$f_{1.3}$				R	R	X	R	R	FR
	$f_{1.4}$					FR	F	F	F	F
	$f_{1.5}$						F	F	F	F
F_2	$f_{2.1}$							FR	FR	FR
F_3	$f_{3.1}$								R	FR
	$f_{3.2}$									FR
	$f_{3.3}$									

Figure 1. *Structural Self-Interaction Matrix*

Step 5: Developing Initial Reachability Matrix

The SSIM developed in step 4 should be transformed into the Reachability Matrix, which shows the dependencies between the pairs of factors in a binary format.

Based on the indications in Table 2, SSIM is converted to the Initial Reachability Matrix, which is shown in Figure 2.

Table 2. *Binary format conversion*

Relationship	f_{ij}	f_{ii}
X	0	0
F	1	0
R	0	1
FR	1	1

The matrix has been named Reachability Matrix because it shows whether any variable is reachable from the remaining variables.

X axis / Y axis		F_1					F_2	F_3		
		$f_{1.1}$	$f_{1.2}$	$f_{1.3}$	$f_{1.4}$	$f_{1.5}$	$f_{2.1}$	$f_{3.1}$	$f_{3.2}$	$f_{3.3}$
F_1	$f_{1.1}$	**1**	1	0	0	0	0	1	1	1
	$f_{1.2}$	0	**1**	0	1	0	0	0	0	0
	$f_{1.3}$	1	1	**1**	0	0	0	0	0	1
	$f_{1.4}$	1	1	1	**1**	1	1	1	1	1
	$f_{1.5}$	1	0	1	1	**1**	1	1	1	1
F_2	$f_{2.1}$	1	1	0	0	0	**1**	1	1	1
F_3	$f_{3.1}$	1	1	1	0	0	1	**1**	0	1
	$f_{3.2}$	1	1	1	0	0	1	1	**1**	1
	$f_{3.3}$	1	1	1	0	0	1	1	1	**1**

Figure 2. Initial Reachability Matrix

Step 6: Incorporating Transitivity and Developing final Reachability Matrix

Euclid [10] had stated that "*Things which are equal to the same things are also equal to one another"*. This is the concept of Transitivity, which is an important feature of ISM.

X axis / Y axis		F_1					F_2	F_3		
		$f_{1.1}$	$f_{1.2}$	$f_{1.3}$	$f_{1.4}$	$f_{1.5}$	$f_{2.1}$	$f_{3.1}$	$f_{3.2}$	$f_{3.3}$
F_1	$f_{1.1}$	**1**	1	1*	1*	1*	1*	1	1	1
	$f_{1.2}$	1*	**1**	1*	1	1*	1*	1*	1*	1*
	$f_{1.3}$	1	1	**1**	1*	1*	1*	1*	1*	1
	$f_{1.4}$	1	1	1	**1**	1	1	1	1	1
	$f_{1.5}$	1	1*	1	1	**1**	1	1	1	1
F_2	$f_{2.1}$	1	1	1*	1*	1*	**1**	1	1	1
F_3	$f_{3.1}$	1	1	1	1*	1*	1	**1**	1*	1
	$f_{3.2}$	1	1	1	1*	1*	1	1	**1**	1
	$f_{3.3}$	1	1	1	1*	1*	1	1	1	**1**

Figure 3. *Final Reachability Matrix*

Step 7: Developing Reachability and Antecedent Sets

The utility of the Reachability Matrix is that it can be used to develop hierarchical restructuring [13]. For this, we have to first define reachability and antecedent sets. A ***reachability set*** is defined for each factor as a set containing factors, which can be reached from that particular factor. In other words, the set for each factor contains factors whose cells in the row pertaining to the variable are allotted "1" in the Reachability Matrix.

An ***antecedent set*** is defined for each factor as a set containing factors, which can reach that particular factor. In other words, the set for each factor contains factors whose cells in the column pertaining to the factor are allotted "1" in the Reachability Matrix. For our example the reachability, antecedent and intersection set for the final Reachability Matrix is given below in table 3.

Table 3. *Reachability, antecedent and intersection sets for final reachability matrix*

Factors	***Reachability Set***	***Antecedent Set***	***Intersection Set***
$f_{1.1}$	$f_{1.1}, f_{1.2}, f_{1.3}, f_{1.4}$ $f_{1.5}, f_{2.1}, f_{3.1}, f_{3.2}$ $f_{3.1}$	$f_{1.1}, f_{1.3}, f_{1.4}$ $f_{1.5}, f_{2.1}, f_{3.1}, f_{3.2}$ $f_{3.1}$	$f_{1.1}, f_{1.2}, f_{1.3}, f_{1.4}$ $f_{1.5}, f_{2.1}, f_{3.1}, f_{3.2}$ $f_{3.1}$
$f_{1.2}$	$f_{1.1}, f_{1.2}, f_{1.3}, f_{1.4}$ $f_{1.5}, f_{2.1}, f_{3.1}, f_{3.2}$ $f_{3.1}$	$f_{1.1}, f_{1.2}, f_{1.3}, f_{1.4}$ $f_{1.5}, f_{2.1}, f_{3.1}, f_{3.2}$ $f_{3.1}$	$f_{1.1}, f_{1.2}, f_{1.3}, f_{1.4}$ $f_{1.5}, f_{2.1}, f_{3.1}, f_{3.2}$ $f_{3.1}$
$f_{1.3}$	$f_{1.1}, f_{1.2}, f_{1.3}, f_{1.4}$ $f_{1.5}, f_{2.1}, f_{3.1}, f_{3.2}$ $f_{3.1}$	$f_{1.1}, f_{1.2}, f_{1.3}, f_{1.4}$ $f_{1.5}, f_{2.1}, f_{3.1}, f_{3.2}$ $f_{3.1}$	$f_{1.1}, f_{1.2}, f_{1.3}, f_{1.4}$ $f_{1.5}, f_{2.1}, f_{3.1}, f_{3.2}$ $f_{3.1}$
$f_{1.4}$	$f_{1.1}, f_{1.2}, f_{1.3}, f_{1.4}$ $f_{1.5}, f_{2.1}, f_{3.1}, f_{3.2}$ $f_{3.1}$	$f_{1.1}, f_{1.2}, f_{1.3}, f_{1.4}$ $f_{1.5}, f_{2.1}, f_{3.1}, f_{3.2}$ $f_{3.1}$	$f_{1.1}, f_{1.2}, f_{1.3}, f_{1.4}$ $f_{1.5}, f_{2.1}, f_{3.1}, f_{3.2}$ $f_{3.1}$
$f_{1.5}$	$f_{1.1}, f_{1.2}, f_{1.3}, f_{1.4}$ $f_{1.5}, f_{2.1}, f_{3.1}, f_{3.2}$ $f_{3.1}$	$f_{1.1}, f_{1.2}, f_{1.3}, f_{1.4}$ $f_{1.5}, f_{2.1}, f_{3.1}, f_{3.2}$ $f_{3.1}$	$f_{1.1}, f_{1.2}, f_{1.3}, f_{1.4}$ $f_{1.5}, f_{2.1}, f_{3.1}, f_{3.2}$ $f_{3.1}$
$f_{2.1}$	$f_{1.1}, f_{1.2}, f_{1.3}, f_{1.4}$ $f_{1.5}, f_{2.1}, f_{3.1}, f_{3.2}$ $f_{3.1}$	$f_{1.1}, f_{1.2}, f_{1.3}, f_{1.4}$ $f_{1.5}, f_{2.1}, f_{3.1}, f_{3.2}$ $f_{3.1}$	$f_{1.1}, f_{1.2}, f_{1.3}, f_{1.4}$ $f_{1.5}, f_{2.1}, f_{3.1}, f_{3.2}$ $f_{3.1}$
$f_{3.1}$	$f_{1.1}, f_{1.2}, f_{1.3}, f_{1.4}$ $f_{1.5}, f_{2.1}, f_{3.1}, f_{3.2}$ $f_{3.1}$	$f_{1.1}, f_{1.2}, f_{1.3}, f_{1.4}$ $f_{1.5}, f_{2.1}, f_{3.1}, f_{3.2}$ $f_{3.1}$	$f_{1.1}, f_{1.2}, f_{1.3}, f_{1.4}$ $f_{1.5}, f_{2.1}, f_{3.1}, f_{3.2}$ $f_{3.1}$
$f_{3.2}$	$f_{1.1}, f_{1.2}, f_{1.3}, f_{1.4}$ $f_{1.5}, f_{2.1}, f_{3.1}, f_{3.2}$ $f_{3.1}$	$f_{1.1}, f_{1.2}, f_{1.3}, f_{1.4}$ $f_{1.5}, f_{2.1}, f_{3.1}, f_{3.2}$ $f_{3.1}$	$f_{1.1}, f_{1.2}, f_{1.3}, f_{1.4}$ $f_{1.5}, f_{2.1}, f_{3.1}, f_{3.2}$ $f_{3.1}$
$f_{3.3}$	$f_{1.1}, f_{1.2}, f_{1.3}, f_{1.4}$ $f_{1.5}, f_{2.1}, f_{3.1}, f_{3.2}$ $f_{3.1}$	$f_{1.1}, f_{1.2}, f_{1.3}, f_{1.4}$ $f_{1.5}, f_{2.1}, f_{3.1}, f_{3.2}$ $f_{3.1}$	$f_{1.1}, f_{1.2}, f_{1.3}, f_{1.4}$ $f_{1.5}, f_{2.1}, f_{3.1}, f_{3.2}$ $f_{3.1}$

Step 8: Developing Level Partitions

The reachability, antecedent and intersection sets for initial Reachability Matrix are defined for informative and instructive purpose only. It is the final Reachability Matrix that we are interested in for building the digraph. For this, level partitions i.e. different levels based on a series of iterations, are to be developed. Levels starting with the top level contain the variables for which the Reachability and Intersection sets are the same (meaning that both the sets contain the same variables) in each iteration. The top level (***Level 1***) is identified by checking the variables in the final Reachability Matrix for which the reachability and intersection sets are the same [10]. In our case, each factors occupy Level 1. The factors for which the reachability and the intersection sets are the same occupy the top level in the ISM hierarchy and the top level factors are those factors that will not lead the other factors above their own level in the hierarchy [12].

Step 9: Developing Conical Matrix

The Conical Matrix is the step just before building the digraph. It is developed by clubbing together the factors in the same level, across rows and columns of the final Reachability Matrix [12]. What is done here is that on the X-axis and Y-axis, the factors are written down based on their levels starting from Level-1. In our example, the factors in Level-1 being $f_{1.1}$, $f_{1.2}$, $f_{1.3}$, $f_{1.4}$ $f_{1.5}$, $f_{2.1}$, $f_{3.1}$, $f_{3.2}$ $f_{3.1}$, these factors are first written down on the X and Y axes. The Conical Matrix is similar to the Reachability Matrix with the exception that the factors in the Conical Matrix are written on the X- and Y-axes based on their levels. The relationships between the factors are taken from the Reachability Matrix. The Conical Matrix for our case is the same as final Reachability Matrix (figure 3).

Step 10: Building Digraph

Based on the Conical Matrix, the initial Digraph is built. A Digraph is defined as set of nodes (representing the variables in the Conical Matrix) which are interlinked together as per the relationship in the matrix (F, R, FR or X) and all the links are shown as arrows indicating the direction from one node to the other [10].

The final Digraph as shown in Figure 4 is developed after removing the Transitivity Links.

Thus developed Digraph is the structural model of the interrelationships and the interaction between factors that support the process of developing an individual approach to customers.

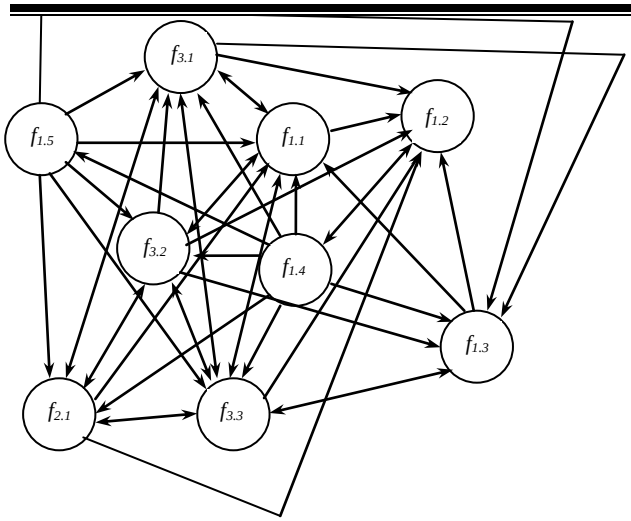

Figure 4. Final Digraph

As can be seen from figure 4 there is a lot of interaction between the factors that help building an individual approach to customers. With the technical support of Industry 4.0 the reporting of the interactions between the factors can be done in real time and thus to build an effective integration of the clients in the process of creating value.

3. Conclusion

In this paper discuses the interrelationships and the interaction between factors, affecting the level of customers Co-Participation, and their integration in a structured way, with the help of the so-called Interpretive Structural Modeling (ISM) to help integrate them into a comprehensive conceptual framework that represents producer-customer interactions under Industry 4.0 conditions and, as a result, increase the efficiency of the process of creating value according to the individual requirements and expectations of the customer.

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INCREASING AND JUSTIFICATION OF DEMAND FOR THE MODERNIZATION OF AGRICULTURAL MACHINERY

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Abstract: *The paper presents a technical and economic background to the need for modernization of modern tractors and combines. The presented method allows forecasting the demand for modernization of equipment. It allows to develop the program of action to improve the quality of machines, assess their real potential, develop of strategic and operational planning for the development of modernization, organize activities of the technical service. This article proposes a method for determining the demand for modernization of agricultural machinery in technical, repair and technical enterprises, based on the analysis of statistical and expert data characterizing their influence on the demand for* research. *It is justified that repair company must confidently organize an active advertising campaign to promote modernized machines to the market.*

KEY WORDS: MEANS OF MECHANIZATION, ANALYTICAL METHOD, COSTS, OPTIMUM, TECHNOLOGY, YIELD.

1. Introduction

One of the most important ways of preserving and increasing the machine-tractor park of Ukraine today is its modernization at the machine-building enterprises. This implies a series of works to improve the quality and economy of machines by replacing individual components to more reliable.

The enterprises of the technical service are widespread re-equipment of tractors of type KhTZ-170, combine harvesters DON-1500B, forage harvesters of German manufacture by engines of brands SMD, YAMZ. The hydraulic system, electric equipment, transmission is being improved, on tractors of type KhTZ-170 the modernization of not only the engine but also the cabs is carried out.

As a result of modernization of technology, its technical level is significantly increased. For the tractors KhTZ-170 provides improved comfort conditions, and the average mean time to failure increases in three-times. The estimated payback period is 2 years. The results of raising the technical level of modernized tractors KhTZ-170 are shown in the table 1.

2. Preconditions and means for resolving the problem

Modernization of tractors KhTZ-170 provides (according to the results of tests on farms) reduction of the cost of fuel consumption – by 10...18%, and an increase in average mean time to failure from 24 to 30 hours.

One of the main advantages of upgraded equipment that was in service is its lower price compared with the new machine and better than the repaired by the usual way and more higher quality characteristics. However, each of the repair companies willing to implement this service faces real demand for it.

Table 1. *Comparative indicators of the technical level of the modernized tractor KhTZ-170*

Indexes	Indicators value	
	basic (BF6M1013E, DEUTZ AG)	upgraded (SMD-62/63)
Engine power, hp / kW	186/139	175/128
Specific fuel mption, g / kW	209	238
Average work time for refusal, h.:		
– internal combustion e	810	750
– flywheel drive	110	120
– chassis transmission	510	600
– rubber products	130	150
Noise level in the cab, dB	85	75
Weight, kg	770	910
Price, USD	9500	3200
Average work time for l, h.	24	30

Like every new activity, modernization requires marketing research that determines the position of the repair enterprise in the market, the characteristics of buyers and sellers, the potential and actual volumes of work, without which knowledge it is impossible to carry out the relevant work. However, in many enterprises of the technical service of marketing work only begin to develop and have not received the necessary distribution. Many still work in olden times. This leads to frequent breakdowns of work plans, disturbed rhythm and balance of production, falling profits, slowing down wage growth, the production scale can not be forecasted, etc.

This article proposes a method for determining the demand for modernization of agricultural machinery in technical, repair and technical enterprises, based on the analysis of statistical and expert data characterizing their influence on the demand for research. The work was done using the Statistika program developed for the regression analysis of ordered, dependent and independent variables. It allows numerically to determine the influence of various factors on the resultant parameter - the demand for the modernization of complex agricultural machinery that was or is in operation. This approach provides for the purposeful management of the mentioned effective parameter, that is, the demand for modernization.

3. Results and discussion

To obtain a universal regression equation for any agricultural tractor, combine harvester and forage harvester, etc. The complex equipment all the raw data were presented in the form of comparative characteristics of modernized machines with refurbished on the farm. For example, the price was accepted as $W = W_m / W_k$, where W_m – price of a modernized machine, and W_k – the price of repair in enterprise, the level of recovery of the resource was determined by the ratio $q = q_m / q_k$ etc. This condition is due to the fact that the main alternative solution today against the modernization of the machine at the enterprise technical service is its repair on the farm.

In recent years, our secondary market has begun to develop a technique for the purchase and sale of old cars. In this regard, the enterprises of the technical service has a new possibility of business organization on the basis of modernization of the write-offs or cars bought at the farms. The written-off technique is bought up by repair companies at residual value, is modernized at restoration and then put on sale.

Such a path of modernization requires a special diligence in the study of demand, as it is associated with the acceptance of repairing

the company of all risks associated not only with the costs of recovering write-off equipment, but also with the subsequent implementation of it in the secondary market.

However, the nature of the decision to purchase a modernized machine and the modernization of equipment operated in the farm, in many respects, is similar and differs not in qualitative factors influencing it, but in their quantitative values, which was taken into account when formulating and solving the problem.

The expediency of sending a machine to a repair enterprise, or purchases in the secondary market at the consumer arises when the total costs for upgrading and subsequent costs of maintenance of the equipment will be less than when repairing the farm. When the conditions of modernization will be more comfortable for the consumer than he can do it himself. Finally, when the consumer will have full confidence in the quality of modernization.

It was from these points of view that market research was conducted based on the study of demand statistics, as well as questioning of specialists of farms and enterprises of technical service, who had experience of this work. The demand for modernization *S* was measured on a ten-point system, from 0 to 10.

As the function arguments, the influence of the following factors was studied:

1) raising the price of modernization – $W = W_m / W_k$;

2) reduction of downtime in repair in conditions of repair enterprise – $t_p = t_{pk} / t_{pm}$;

3) increase of work up to the next capital repair – $q = q_m / q_k$;

4) increase in reliability – $t_o = t_{om} / t_{ok}$;

5) reduction of specific fuel consumption – $\rho = \rho_k / \rho_m$;

6) reducing noise in the workplace and improving other working conditions – $Y = Y_k / Y_m$;

7) reduction of maintenance and repair costs – $C_{tor} = C_{tork} / C_{torm}$;

8) service life of machine for modernization – T_s ;

9) participation in the repair of specialists in the enterprise – k_u ;

10) one-time prepayment – k_{pred} ;

11) distance to repair enterprise – D .

The resulting regression equation for the demand for modernization has the form:

$$S = 3.372 - 1.107W + 0.004t_p + 2.685q + 1.491t_o - 2.799\rho -$$
$$-0.684Y + 2.479C_{tor} - 0.192T_C + 0.348k_u - 0.006k_{pred} + 0.005D.$$

The correlation coefficient of the found dependence is equal to 0.914. Preemptive values *S*: minimal – 1.3101, maximal – 8.5615, average – 5.7576, standard deviation – 1.65961. The obtained coefficients characterizing the variation of parameters indicate a high degree of correspondence between the chosen straightforward regression model and the initial data. Checking the results by substituting the average values of the parameters found showed almost complete convergence of results. With substitution, the average demand was *S* = 5.7206.

The economic assessment of the factors influencing demand is determined by the coefficients of elasticity, which characterize the percentage of the average increase in the value of the effective indicator – the demand for a change in factor ratio by 1%. To do this, use the formula:

$$E_{ki} = X_i \frac{X_{spi}}{S},$$

where X_{spi} – the average value of the corresponding factor indicator; S – the average value of demand; X_i – regression coefficient with the corresponding factor parameter.

The results of calculating the total increase in demand are given in the table 2.

The analysis of the table showed that positive impact on the demand for modernization of equipment makes increasing in post-repair resource and reliability, the negative – the high price and long life of machine to modernization.

The latter factor affects the decline in demand for modernized technology, primarily in the secondary market. There is also some distrust of the indicators, which are declared by repair enterprises on quality.

Table 2. *Private coefficients of elasticity of the regression model of demand for modernization of agricultural machinery*

Factor	Symbolic designation	Average value of indicator, X_{spi}	Regression coefficient, X_i	Elasticity factor, E_{ki}
Demand for modernization	S	5.7576		
Increasing the price of modernization	W	2.1052	-1.107	-0.40476
Lowering downtime in repairs in a repair enterprise	t_p	40.3788	0.004	0.02805
Increase of work up to the next capital repair	q	1.7939	2.685	0.083657
Improve reliability	t_o	1.5409	1.491	0.39903
Reduce specific fuel consumption	ρ	1.1758	-2.799	-0.57160
Improvement of working conditions	Y	1.1727	-0.684	-0.13932
Reduced maintenance and repair costs	C_{tor}	1.1861	2.479	0.51069
Service life of the machine for upgrading	T_c	9.7576	-0.192	-0.32539
Participation in the repair of specialists of the enterprise	k_u	0.4242	0.348	0.02564
One-time prepayment, %	k_{pred}	45.1515	-0.006	-0.04705
Distance to repair enterprise	D	110.6061	0.005	0.096052

In fig. 1 presents the results of calculating the demand for tractors XT3-170, restored after the depreciation period and write-off, for sale in the secondary market.

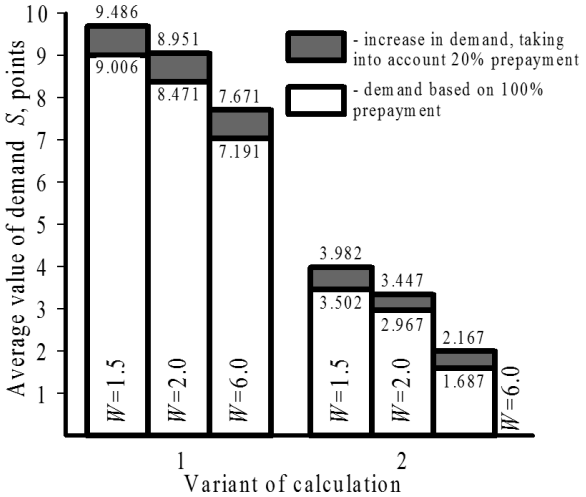

Fig. 1. *– Dynamics of demand for machine modernization on secondary market at level of resource recovery: 1 – q_m = 0.85; 2 – q_m = 0.60*

Positive factors include fuel economy, improved working conditions, and reduced maintenance downtime. The factors that increase the demand also include the participation of specialists in modernization of equipment, including in order to control the quality of modernization, partial instead of full prepayment for the work performed. Increasing demand while reducing the distance to the object of modernization may be interpreted not only by the

limited radius of service of machine-building enterprises, for example, SBK «Druzhba» of the Melitopol district of Zaporizhzhya region, but also the necessity in certain cases of modernization of equipment in the conditions of the farm, which in really is used by some enterprises.

From the graph shows that an increase in the quality tractors that comprehensively characterized coefficient of recovery resources 0.85, and setting prices modernized machine that does not exceed 50% of the price of new (1 version of the calculation), the demand for modernized tractor HTZ-170 ranged from 7.0 to 9.5 points. With decreasing quality (q_m = 0.6), demand drops to 1.7...4.0 points (2 variants of calculation).

The 1st version of the calculation characterizes the quality indicators of the modernized tractor, established according to the State Standard of Ukraine. The 2nd version of the calculation may correspond to the actual performance of the modernized tractors, or the estimated estimates of consumers of these indicators, based on the experience of major repairs of tractors at the repair enterprise.

If the quality of the upgraded machines does not correspond to the one declared, the repair company should be extremely careful with it on the market, because the identified flaws can have a significant impact on the reduction of demand and loss of image. In case of compliance of the quality indicators with the requirements of the State Standard of Ukraine, the repair company must confidently organize an active advertising campaign to promote these machines to the market.

4. Conclusions

Thus, the presented methodology allows predicting the demand for modernization of equipment, which is necessary for the development of a program of actions of enterprises for improving the quality of machines, assessing their real capabilities, developing strategic and operational plans for modernization, organization of activities in the technical service market.

The application of the described methodology for increasing demand for equipment modernization will significantly increase it, which will undoubtedly affect both the efficiency of the use of machine and tractor unit of consumers, and the increase of economic effect of te machine-building enterprises of the region.

Research of demand problems in modernization of machines in our opinion needs more advertising influences on this issue. Agricultural producers have not even heard about this, and this direction is being seriously promoted in the SBK «Druzhba». The idea of modernizing agricultural machinery is also one of the methods to restore the shortage of technology in the countryside, as well as resource saving.

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ELASTIC AND STATIC CHARACTERISTICS OF INNOVATIVE BALISTIC BORON CARBIDE CERAMIC ARTICLES

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Abstract: Boron carbide ceramic products are made using an innovative technology and their elastic and static properties are tested. The products are of different shape and thickness and can be user to build the front layer of macro dispersal ceramic-polymer modular systems for individual protection and for armoring of military land and air mobile and stationary objects.

Keywords: ELASTIC CHARACTERISTICS, BALTIC BORON CARBIDE CERAMICS, MACRO DISPERSAL MODULAR PROTECTION SYSTEMS

I. Introduction

The structural elements made of pure boron carbide have an extremely wide range of physicochemical and mechanical properties, which make them unmatched in many technological areas. Their high hardness (third in order after the diamond and the boron nitride), the values of their modulus of elasticity, the speed of sound propagation in them, and their low relative weight make them a leader in the construction of multilayer ceramic polymer systems for protection against high-speed kinetic impact [1] .

At present, research into the synthesis of pure boron carbide and the production and the properties of articles made from it is being given a great deal of attention in various larger and smaller countries around the world.

Particular attention is paid to the improvement of the hot pressing method. Bulgaria is one of the countries where innovative production of boron carbide ceramic parts is carried out.

The Technological Center Nomat Ltd., Burgas and a team from MSETHC"Acad. A. Balevski "- Bulgarian Academy of Sciences produce boron carbide ceramic articles and study their physico mechanical and elastic properties and the ballistic characteristics of modular ceramic polymer protective systems based on boron carbide [2].

The products are made using innovative technology, including the use of pure boron carbide with a specific sediment composition.

II. Determination of the elastic properties of ceramic parts made of boron carbide.

1. Subject of study - square tiles with thickness 8 and 10 mm with a 50 mm side length, a total of 40 pieces.

2. Investigation methods.

Two investigation methods have been applied to characterize the elastic properties of ceramic composite plates:

- Ultrasonic method
- Vibration method

2.1. Ultrasonic method for determining the elastic properties of boron carbide plates

Determination of dynamic elastic material modules by ultrasound is based on the dependencies (1), (2), (3) between the velocities of longitudinal (C_L) and transverse (C_S) ultrasonic waves, the density (ρ), the linear deformation modules (E)) and shear modulus (G), the Poisson coefficient (μ) derived from the mechanical wave propagation equations in isotropic medium [3,4]:

$$E = 4\rho C_s^2 \left(\frac{\frac{3}{4} - \left(\frac{C_S}{C_L}\right)^2}{1 - \left(\frac{C_s}{C_L}\right)^2} \right) \quad (1)$$

$$G = \rho C_s^2 \quad (2)$$

$$\mu = \frac{\frac{1}{2} - \left(\frac{C_s}{C_L}\right)^2}{1 - \left(\frac{C_s}{C_L}\right)^2} \quad (3)$$

The ultrasound wave velocities are determined by measuring the propagation time of waves. Ultrasonic wave velocity device consists of an ultrasonic apparatus and ultrasonic transducers for longitudinal and transverse waves. The measurements of longitudinal waves have been performed at frequency 10 MHz using an echo method. The transverse wave measurements have been made by through transmission method at 3.5 MHz .

Relative errors in the determination of propagation time and ultrasound wave velocity in the reference sample are less than 1%. Accuracy of measurements is up to 2%. The measurements were made on the two preliminary polished plates from each type of materials. The presented results are averaged on the 5 measurements and shown by type of plates in Table 1.

Table 1. *Results from ultrasonic testing and elastic constants calculated by Eq.1-3. Plates 50x50x8mm*

No	, kg/m3	C_L,m/s	C_s,m/s	μ	G,Pa	E, Pa
8.1	2597	11890	7500	0.17	1.5E+11	3.67E+11
8.2	2544	11442	7570	0.17	1.5E+11	3.65E+11
8.3	2549	11890	7790	0.12	1.6E+11	3.60E+11
8.4	2586	12024	7690	0.16	1.5E+11	3.79E+11
8.5	2586	11562	7250	0.21	1.4E+11	3.71E+11
8.6	2526	11737	7590	0.15	1.4E+11	3.52E+11
8.7	2606	11977	7690	0.15	1.5E+11	3.74E+11
8.8	2532	11798	7390	0.18	1.4E+11	3.58E+11
8.9	2594	11723	7690	0.14	1.5E+11	3.67E+11
8.10	2546	12060	7367	0.20	1.4E+11	3.73E+11
8.11	2531	11811	7450	0.17	1.4E+11	3.53E+11
8.12	2563	11080	7560	0.15	1.5E+11	3.15E+11
8.13	2567	11480	7690	0.15	1.5E+11	3.38E+11
8.14	2482	12011	7206	0.22	1.3E+11	3.58E+11
8.15	2575	11617	7405	0.16	1.4E+11	3.48E+11
8.16	2537	11731	7390	0.17	1.4E+11	3.49E+11
8.17	2541	11790	7600	0.13	1.5E+11	3.48E+11
8.18	2542	11856	7705	0.14	1.5E+11	3.59E+11
8.19	2580	11790	7696	0.13	1.5E+11	3.59E+11
8.20	2596	12000	7694	0.15	1.5E+11	3.74E+11
Aver.	2559	11763	7546	0.15	1.5E+11	3.8 E+11
StDev.	31.36	241	166	0.15	1.E+11	3.36E+11

Table 2. *Results from ultrasonic testing and elastic constants Plates 50x50x10mm*

No	ρ,kg/m3	CL,m/s	Cs,m/s	μ	G,Pa	E, Pa
10.1	2524	11980	7800	0.17	1.46E+11	3.4E+11
10.2	2473	11788	7700	0.17	1.46E+11	3.8E+11
10.3	2424	11998	7500	0.12	1.55E+11	3.7E+11
10.4	2502	11926	7940	0.16	1.53E+11	3.6E+11
10.5	2519	11946	7620	0.21	1.36E+11	3.7E+11
10.6	2524	11941	7712	0.15	1.46E+11	3.8E+11
10.7	2467	11960	7700	0.15	1.54E+11	3.5E+11
10.8	2484	11993	7620	0.19	1.38E+11	3.8E+11
10.9	2465	11919	7699	0.14	1.53E+11	3.7E+11
10.10	2456	11996	7750	0.20	1.38E+11	3.8E+11
10.11	2518	11973	7720	0.17	1.4E+11	3.6E+11
10.12	2443	11935	7666	0.17	1.46E+11	3.7E+11
10.13	2547	12013	7735	0.16	1.52E+11	3.6E+11
10.14	2435	11960	7690	0.20	1.29E+11	3.8E+11
10.15	2576	12022	7700	0.16	1.41E+11	3.7E+11
10.16	2521	11957	7680	0.17	1.39E+11	3.8E+11
10.17	2464	11935	7690	0.13	1.47E+11	3.5E+11
10.18	2398	11994	7450	0.14	1.51E+11	3.8E+11
10.19	2526	11903	7940	0.14	1.53E+11	3.8E+11
10.20	2558	11959	7700	0.15	1.54E+11	3.9E+11
Average	2491	11961	7701	0.16	1.53E+11	3.7E+11
StDev	48	66.29	114	0.15	1.E+11	5.6E+11

2.2. Vibration method for determination of elastic properties for boron carbide plates.

The impulse excitation method is a new technique for determination of dynamic elastic properties of materials. The applicability of the resonance method depends on knowledge of the frequency equations relating the natural frequencies of test specimens, dynamic elastic properties and density of the material. These relations are solutions of a differential equation, which depend on the boundary conditions and shape of the specimen [5-7]. Procedures and recommendations for the elastic characterization of isotropic materials using free-edge test specimens like bars, rods, and circular plates are specified in ASTM Standards 1876.

In our work we use expression for estimating the natural frequencies of plates with freely supported boundary conditions [5,6]:

$$f = \frac{\pi}{2}\sqrt{\frac{D}{\rho h}}\frac{\lambda}{a^2} \quad (4)$$

Where f is the natural frequency in Hz, λ is a dimensionless natural frequency factor for freely supported plate [7,8], D is the plate flexural rigidity, ρ is the density, h and a are the thickness and width of the square plate, E is modulus of elasticity, μ is the Poisson's ratio of the material of the plate. The frequency factors λ depend on the ratio of length and width of the plate as well as on Poisson's ratio, if one or more edges of the plate are free.

$$D = \frac{Eh^3}{12(1-\mu^2)} \quad (5)$$

Eq. (4,5) allow the calculation of natural frequencies of plates having any combination of free, clamped, or simply supported edges, if the elastic constants are given as well as determination of the elastic modulus.

The values of the frequency factors λ are chosen from [7,8] for various values of Poisson's ratio , defined geometry of the plate, and fixed values of density of material.

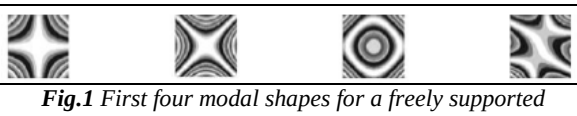

Fig.1 *First four modal shapes for a freely supported isotropic plate*

Experimental modal analysis

The test device for experimental modal analysis is shown in Fig. 2. The exciting impulse is produced by striking the plate with a suitable hammer. As a pickup transducer is used acoustic microphone which signals are addressed to personal computer. After signal processing the values of the natural frequencies of vibration are obtained.

The specimens used in the experimental modal analysis are 16 plates 50 mm x 50 mm x 8 mm and 15 plates 50 mm x 50 mm x 10 mm. For reference sample we use aluminum square plate with the same dimensions.

The specimen is impacted to position 1 and microphone is located in position 9 (fig. 1). The frequency response function curve is plotted and natural frequencies are obtained. Fig. 3 shows frequency response function for the first node of boron carbide plate N5.

Young's modulus is derived expressed using the formula (4)

$$E = \frac{48}{\pi^2}\left(\frac{f}{\lambda(\mu)}\right)^2 \frac{ma^2(1-\mu^2)}{h^3} \quad (6)$$

where f is the natural frequency, m is the mass of the specimen, a is the length of the plate, h is the thickness, and λ is a non-dimensional factor obtained from [8,9].

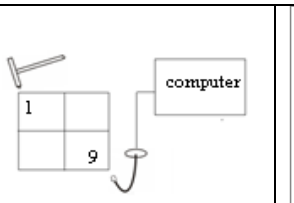

Fig.2 *Experimental setup*

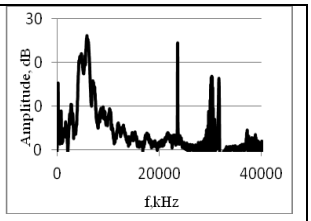

Fig.3. *Frequency response function for the first node of boron carbide plate 5.*

The first resonance frequency was used in the calculations. The relative errors between the analytical and experimental frequencies of the freely supported plates can be calculated using the formula

$$Error = \frac{f_E - f_T}{f_E}, \% \quad (7)$$

where: $\mathbf{f_E}$ is the experimental natural frequency obtained through modal analysis ; $\mathbf{f_T}$ is the theoretical natural frequency obtained by equation (4).

Comparisons between experimental and theoretical natural frequencies as well as the values of the elastic constants calculated by Eq.7 are presented in the Table 3 and 5.

Table 3.*Comparisons between experimental and theoretical first natural frequencies and values of elastic constants for some of investigated plates 50x50x8 mm.*

	f1 теор.,Hz	f1 exp,Hz	Error,%	E, Pa
8.1	25384.9	23888.5	2.4	3.9E+11
8.2	25599.69	22514.62	0.1	3.6E+11
8.3	25337.67	24928.59	5	3.7E+11
8.4	25934.48	25395.75	1.5	3.5E+11
8.5	24968.4	24288.2	2.9	3.9E+11
8.6	25429.61	24468.96	2.8	3.5E+11
8.7	25904.48	25213.14	-1.7	3.8E+11
8.8	25358.14	23808.83	-0.2	3.5E+11
8.9	25551.77	19169.84	1.3	3.8E+11
8.10	24908.48	23276.63	2.1	3.7E+11
8.11	25317.1	19839.75	2.9	3.7E+11
8.12	24168.62	24242.77	7.4	3.9E+11
8.13	24911.93	24030.11	-4.7	3.8E+11
8.14	24600.9	14855.83	5.8	3.9E+11
8.15	24788.04	23302.44	3.6	3.8E+11
8.16	24928.13	23927.13	5.4	3.8E+11
Average				3.8E+11
StDev				1.9E+10

Table 4. *Comparisons between experimental and theoretical first natural frequencies and elastic modulus for some boron carbide plates 50x50x10 mm*

N 10	f1 теор., Hz	f1 exp, Hz	Error, %	E, Pa
1	32346.65	33365	3.1	3.7E+11
2	31538.53	33301	5.3	3.9E+11
3	31804.35	33279	4.4	3.8E+11
4	32078.27	33354	3.8	3.98E+11
5	31924.26	33301	4.2	3.97E+11
6	31920.35	33570	5.0	3.8E+11
7	32011.37	32390	1.2	3.5E+11
8	31730.73	33365	5.0	3.7E+11
9	31874.00	33269	4.2	3.8E+11
10	31901.73	33312	4.2	3.9E+11
11	31915.77	33419	4. 5	3.7E+11
12	31807.57	33311	4.5	3.9E+11
18	31602.71	32310	2.2	3.9E+11
19	32095.55	33365	3.8	3.8E+11
20	32224.30	33290	3.2	3.8E+11
Average				3.9E+11
StDev				1.33E+10

Figure 4 *illustrates good agreement between the values of elastic modulus obtained by ultrasound and vibration method.*

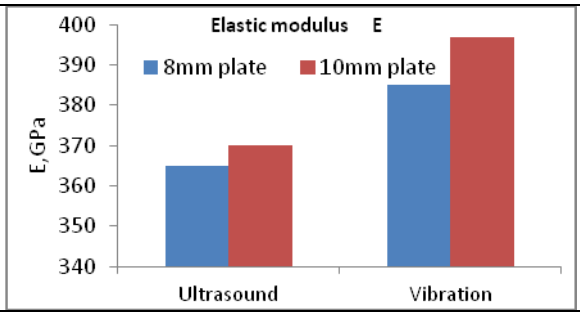

Fig.4. Elastic characteristics E, obtained by ultrasonic and vibration methods

The values of elastic modules of boron carbide ceramic specimens are approximately 400 GPa (380 ± 20 GPa).

3. Measuring the Rockwell hardness number H_{Rc} of 50 x 50 x 8 mm boron carbide plates with Indentor w (a diamond cone).

Tab. 5. *Results of the hardness measurement of 20 test specimens.*

Spec. No	8.1	8.2	8.3	8.4	8.5	8.6	8.7	8.8	8.9	8.10
Value ?	**94,0**	**95,5**	**93,0**	**90,5**	**93,0**	**71,0**	**65,5**	**90,0**	**98,0**	**69,0**
Spec. No	8.11	8.12	8.13	8.14	8.15	8.16	8.17	8.18	8.19	8.20
Value ?	**98,0**	**98,0**	**98,0**	**97,0**	**98,0**	**98,0**	**95,5**	**97,0**	**93,0**	**96,0**

4. Measuring the Rockwell hardness number H_{Rc} of 50 x 50 x 10 mm boron carbide plates using Indentor w (a diamond cone).

Tab. 6. Results of the hardness measurement of 20 test specimens.

Spec. No	10.1	10.2	10.3	10.4	10.5	10.6	10.7	10.8	10.9	10.10
Value HRC	**97,5**	**96,5**	**97,5**	**97,0**	**94,5**	**95,5**	**93,5**	**78,5**	**96,0**	**97,0**
Spec. No	10.11	10.12	10.13	10.14	10.15	10.16	10.17	10.18	10.19	10.20
Value HRC	**98,0**	**98,0**	**98,0**	**97,0**	**98,0**	**98,0**	**95,5**	**97,0**	**93,0**	**96,0**

5. Examination of the compressive strength of boron carbide samples measuring 10 x 10 x 10 mm.

Tab. 7. Results of the hardness measurement of 10 test specimens.

Spec. No.	1	2	3	4	5	6	7	8	9	10
Valume σ, MPa	**1800**	**1840**	**1840**	**1820**	**1850**	**1840**	**1800**	**1810**	**1830**	**1820**

III. Conclusions

The conducted study of the elastic and static characteristics of boron carbide products shows that their values exceed those of standard ballistic ceramic materials, which is a prerequisite for achieving a high effect in creating hybrid modular protective systems using the obtained boron carbide products.

Based on the information obtained from the conducted studies, as well as on the results regarding the created boron carbide ceramic compositions, the improved production conditions, respectively the physical and physical-mechanical parameters of the sample batches show that the developed technology and compositions possess the indicators that allow their use for ballistic purposes.

From the investigated ballistic ceramic material, a functional multi-layer system has been designed to protect against high-speed effects. The weight of one unit of armored protective area is lower than the weight of the equivalent corundum bumper.

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LIMITATIONS TO SUSPENSION PERFORMANCE IN A TWO-DEGREE-OF-FREEDOM CAR ACTIVE SUSPENSION

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Abstract: *It is often assumed that if practical difficulties are neglected, active systems could produce in principle arbitrary ideal behavior. This paper presents the factorization approach that is taken to derive limitations of achievable frequency responses for active vehicle suspension systems in terms of invariant frequency points and restricted rate of decay at high frequencies. The factorization approach enables us to determine complete sets of such constraints on various transfer functions from the load and road disturbance inputs for typical choices of measured outputs and then choose the "most advantageous" vector of the measurements from the point of view of the widest class of the achievable frequency responses. Using a simple linear two degree-of-freedom car suspension system model it will be shown that even using complete state feedback and in the case of in which the system is controllable in the control theory sense, there still are limitations to suspension performance in the fully active state.*

Keywords: VEHICLE, ACTIVE SUSPENSION, CONTROL, LIMITATIONS, PARAMETRIZATION

1. Introduction

Two major performance requirements of suspension are to improve ride and handling quality when random road and load disturbances from the environment act upon running vehicles. Automotive suspensions are designed to provide good vibration insulation of the passengers and to maintain adequate adherence of the wheel for braking, accelerating and handling, i.e. the purpose of active suspensions in terms of performance is to improve both of these conflicting requirements.

In this paper, it will be shown the factorization approach taken to derive limitations of achievable frequency responses for active vehicle suspension systems. As we will see, limitations derived for a traditional one-quarter-car model (Fig.1) in the frequency domain arise in the form of invariant frequency points and restricted rate of decay at zero and infinite frequencies.

Youla-Kucera factorization approach to feedback system stability has been shown in [2], [3] to derive achievable dynamic responses for active suspension systems of vehicles. Complete sets of constraints on various transfer functions from the road and load disturbance inputs were derived for typical choices of measured outputs.

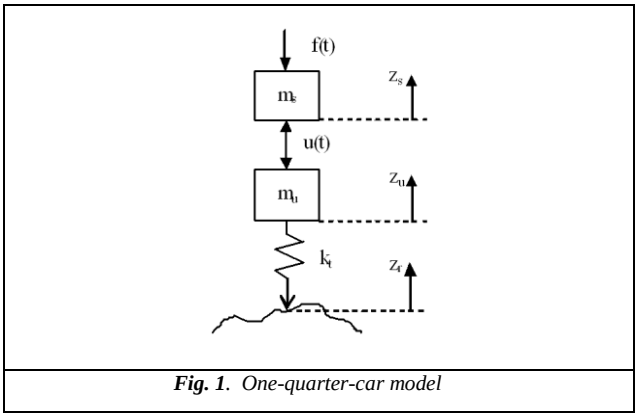

Fig. 1*. One-quarter-car model*

The approach was illustrated for the one-quarter-car model shown in Fig.1, where:

- *u(t)* control input (active suspension force) [N]
- m_u weight of the unsprung mass (wheel) [kg]
- m_s weight of the sprung mass supported by each wheel and taken as equal to a quarter of the total body mass [kg]
- k_t stiffness of the tire [N/m]
- $z_r(t)$ road displacement (road disturbance) [m]
- $z_s(t)$ displacement of the sprung mass [m]
- $z_u(t)$ displacement of the unsprung mass [m]
- *f(t)* load disturbance [N]

Note that if the one-quarter-car model contains also a passive suspension system (a sprung of stiffness k and a shock absorber of damping quotient b then the active suspension force u(t) involves also the adequate force generated by the passive suspension system.

On the base of the Youla-Kucera parametrization, complete sets of limitations were derived for transfer functions from the road disturbance input (load f(t) is absent):

$$H_{zw}^{1}(s) = \frac{Z_s(s)}{Z_r(s)}\Big/_{f=0} \qquad \text{(to the sprung mass position)} \qquad (1)$$

$$H_{zw}^{2}(s) = \frac{Z_s(s)-Z_u(s)}{Z_r(s)}\Big/_{f=0} \quad \text{(to the suspension deflection)} \quad (2)$$

$$H_{zw}^{3}(s) = \frac{Z_u(s)-Z_r(s)}{Z_r(s)}\Big/_{f=0} \quad \text{(to the tire deflection)} \qquad (3)$$

and analogically for the load disturbance input for various choices of measured outputs even for full state feedback.

2. Comprime Factorization

Consider the standard feedback configuration shown in Fig.2,

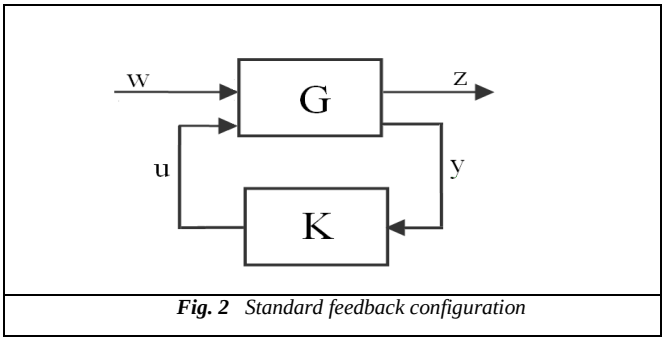

Fig. 2 *Standard feedback configuration*

where *w* is the exogenous input, typically consisting of disturbances and sensor noises, *u* is the control signal, *z* is the output to be controlled, and *y* the measured output. In general, *u*, *w*, *y*, and *z* are vector-valued signals.

The transfer matrices *G(s)* and *K(s)* are, by assumption, real-rational and proper: *G* represents a generalized plant, the fixed part of the system, and *K* the controller [4]. Partition *G(s)* as:

$$G(s) = \begin{bmatrix} G_{11}(s) & G_{12}(s) \\ G_{21}(s) & G_{22}(s) \end{bmatrix} \qquad (4)$$

Then Fig.2 stands for the following algebraic equations:

$$Z(s) = G_{11}(s)W(s) + G_{12}(s)U(s) \quad (5)$$

$$Y(s) = G_{21}(s)W(s) + G_{22}(s)U(s) \quad (6)$$

$$U(s) = K(s)Y(s) \quad (7)$$

Manipulating the equations listed above, the following transfer function $T_{zw}(s)$ from w to z as a linear-fractional transformation of $K(s)$ can be derived:

$$T_{zw} = G_{11} + G_{12}K[I - G_{22}K]^{-1}G_{21} = \\ = G_{11} + G_{12}[I - KG_{22}]^{-1}KG_{21} \quad (8)$$

It is shown in [1] that the set of all proper real-rational matrices $K(s)$ stabilizing $G(s)$ is parametrized by a free parameter $Q(s) \in RH_\infty$ as follows:

$$K = [Y - MQ][X - NQ]^{-1} = \\ = \left[\tilde{X} - Q\tilde{N}\right]^{-1}\left[\tilde{Y} - Q\tilde{M}\right] \quad (9)$$

where:

$$\mathrm{M}(s), N(s), X(s), Y(s) \in RH_\infty,$$

and $\tilde{M}(s), \tilde{N}(s), \tilde{X}(s), \tilde{Y}(s) \in RH_\infty$ can be found by comprime factorization approach of $G_{22}(s)$:

$$G_{22}(s) = N(s)M^{-1}(s) = \tilde{M}^{-1}(s)\tilde{N}(s) \quad (10)$$

$$\begin{bmatrix} \tilde{X}(s) & -\tilde{Y}(s) \\ -\tilde{N}(s) & \tilde{M}(s) \end{bmatrix}\begin{bmatrix} M(s) & Y(s) \\ N(s) & X(s) \end{bmatrix} = I \quad (11)$$

Substituting the equation (9) into (8) we obtain the transfer matrix $\mathrm{T_{zw}}(s)$ from w to z in terms of the free parameter $Q(s) \in RH_\infty$:

$$T_{zw}(s) = \\ = G_{11}(s) + G_{12}(s)M(s)\left[\tilde{Y}(s) - Q(s)\tilde{M}(s)\right]G_{21}(s) = \\ = G_{11}(s) + G_{12}(s)[Y(s) - M(s)Q(s)]\tilde{M}(s)G_{21}(s) \quad (12)$$

As the parameter $Q(s)$ varies over the set of all stable proper functions, the equation (12) parametrizes all achievable transfer functions $T_{zw}(s)$.

If it is assumed that the tire does not leave the ground, for the one-quarter car model (Fig.1) the linear differential equations of motion are:

$$m_s\ddot{z}_s = u - f \quad (13)$$

$$m_u\ddot{z}_u = -u + k_t(z_r - z_u) \quad (14)$$

where z_u and z_s are measured from the static equilibrium position.

First, let the load disturbance is absent ($f=0$). Adding equations (13) and (14) we obtain the invariant equation of:

$$m_s\ddot{z}_s + m_u\ddot{z}_u = k_t(z_r - z_u) \quad (15)$$

that is independent on the suspension force u. The following transfer functions will be investigated:

$$H_{SP}(s) = Z_s(s)/Z_r(s) \quad (16)$$

$$H_{SD}(s) = [Z_s(s) - Z_u(s)]/Z_r(s) \quad (17)$$

$$H_{TD}(s) = [Z_u(s) - Z_r(s)]/Z_r(s) \quad (18)$$

3. Invariant Properties

Manipulating the equation (15) we can derive the following invariant identities:

$$[(m_u + m_s)s^2 + k_t]H_{SP}(s) - [m_us^2 + k_t]H_{SD}(s) = k_t \quad (19)$$

$$m_ss^2H_{SP}(s) + [m_us^2 + k_t]H_{TD}(s) = -m_{\,u}s^2 \quad (20)$$

$$[(m_u + m_s)s^2 + k_t]H_{TD}(s) + m_ss^2H_{SD}(s) = \\ = -(m_u + m_s)s^2 \quad (21)$$

It is obvious from (19) and (20) that the sprung mass position transfer function H_{SP} has an invariant "tire-hop" frequency at $\omega_1 = \sqrt{k_t/m_u}$, where:

$$H_{SP}(s)/_{s=j\,\omega_1} = -m_u/m_s \quad (22)$$

Similarly, from (16) and (18) the suspension deflection transfer function H_{SD} has an invariant "rattle-space" frequency at $\omega_2 = \sqrt{k_t/(m_u + m_s)}$ and:

$$H_{SD}(s)/_{s=j\,\omega_2} = -(1 + m_u/m_s) \quad (23)$$

Finally, from (20) and (21), the tire deflection transfer function H_{TD} does not have any invariant frequency point except $\omega_3 = 0$, where:

$$H_{TD}(s)/_{s=j\,\omega_3} = 0 \quad (24)$$

4. Transfer Functions Limitations

In the next, consider the standard block diagram shown in Fig.2.

As an example, consider:

$$w=z_r\,,\ z=z_s \qquad \underline{y} = [\dot{z}_u, z_s - z_u, z_u - z_r]^T.$$

Then:

$$G(s) = \begin{bmatrix} G_{11}(s) & G_{12}(s) \\ G_{21}(s) & G_{22}(s) \end{bmatrix} = \\ = \begin{bmatrix} 0 & \frac{1}{m_ss^2} \\ \begin{bmatrix} \frac{sk_t}{m_us^2+k_t} \\ \frac{-k_t}{m_us^2+k_t} \\ \frac{-m_us^2}{m_us^2+k_t} \end{bmatrix} & \begin{bmatrix} \frac{-s}{m_us^2+k_t} \\ \frac{(m_u+m_s)s^2+k_t}{m_ss^2(m_us^2+k_t)} \\ \frac{-1}{m_us^2+k_t} \end{bmatrix} \end{bmatrix} \quad (25)$$

The limitations of all achievable closed-loop transfer functions $T_{zw}(s) = H_{SP}(s)$ are derived from the right and left comprime factorization of $G_{22}(s)$, i.e.:

$$G_{22} = \underbrace{\begin{bmatrix} \frac{-m_ss^3}{p_4(s)} \\ \frac{(m_u + m_s)s^2 + k_t}{p_4(s)} \\ \frac{-m_ss^2}{p_4(s)} \end{bmatrix}}_{\hat{N}(s)} \underbrace{\left[\frac{m_ss^2(m_us^2 + k_t)}{p_4(s)}\right]^{-1}}_{\hat{M}^{-1}(s)} = \\ = \underbrace{\begin{bmatrix} \frac{m_ss}{p_2(s)} & \frac{m_ss^2}{p_2(s)} & 0 \\ 0 & \frac{m_um_ss^2}{p_2(s)} & \frac{-m_sk_t}{p_2(s)} \\ \frac{-1}{p_2(s)} & 0 & \frac{s}{p_2(s)} \end{bmatrix}^{-1}}_{\hat{M}^{-1}} \underbrace{\begin{bmatrix} \frac{1}{p_2(s)} \\ \frac{m_u+m_s}{p_2(s)} \\ 0 \end{bmatrix}}_{\hat{N}(s)} \quad (26)$$

where $p_2(s)$ and $p_4(s)$ are Hurwitz polynomials of degree 2 and 4, respectively. Then:

$$H_{SP}(s) = \\ = G_{11}(s) + G_{12}(s)M(s)\left[\tilde{Y}(s) - Q(s)\tilde{M}(s)\right]G_{21}(s) = \\ = -\frac{1}{p_4(s)}\tilde{Y}(s)\begin{bmatrix} -sk_t \\ k_t \\ m_us^2 \end{bmatrix} + \frac{s(m_us^2+k_t)}{p_4(s)}Q^*(s) \quad (27)$$

where $Q^*(s) = \left[\frac{Q_3(s)}{p_2(s)}\right]$, $Q(s) = [Q_1(s)\ Q_2(s)\ Q_3(s)]$.

It follows from (27) that thanks to the term $\left[\tilde{Y}(s) - Q(s)\tilde{M}(s)\right]$ bounded for large s:

$$\lim_{s\to\infty} s^2H_{SP}(s) < \infty \quad (28)$$

i.e., the resulting rate of decay is of second degree:

$$H_{SP}(s)/_{s\to\infty} = O(s^{-2}) \quad (29)$$

It is obvious from (27) that the member $\frac{s(m_u s^2+k_t)}{p_4(s)}$ has two imaginary axis zeros - at s=0 and $s = j\omega_1 = j\sqrt{k_t/m_u}$- which can not be canceled by the denominator of $Q^*(s) \in RH_\infty$. With respect to (27) and the Bezout identity (11) it follows, that:

$$H_{SP}(s)/_{s=0} = -\frac{1}{p_4(s)}\tilde{Y}(s)\begin{bmatrix}-sk_t\\ k_t\\ m_u s^2\end{bmatrix}/_{s=0} =$$

$$= -\frac{k_t}{p_4(s)}\tilde{Y}_2(s)/_{s=0} = 1 \quad (30)$$

and similarly:

$$H_{SP}(s)/_{s=j\omega_1} = -\frac{1}{p_4(s)}\tilde{Y}(s)\begin{bmatrix}-sk_t\\ k_t\\ m_u s^2\end{bmatrix}/_{s=j\omega_1} =$$

$$= -m_u/m_s \quad (31)$$

This result endorses (25).

Thanks to the first order of the imaginary axis zero at s=0, the first derivative of the transfer function $H_{SP}(s)$ does not have any similar restrictions at this point. Expressions (29), (30) and (31) create the complete set of limitations which any admissible transfer function $H_{SP}(s) \in RH_\infty$ must satisfy. Another words, if any complex transfer function satisfies the mentioned limitations, there exists a stabilizing controller $K(s)$ so that $T_{zw}(s) = H_{SP}(s)$. It does not depend on what variables are chosen as the measured output - the limitations always arise in the form of invariant frequency points as was shown in paragraph 3 and in the form of restricted rate of decay at infinite frequencies as shown in (29).

Complete sets of limitations for the transfer functions $H_{SD}(s)$ and $H_{TD}(s)$ can be similarly carried out from the corresponding transfer functions $G(s)$ or using (26), (27), (28) and the corresponding invariant equation stated above. That way the following complete sets of limitations can be derived:

$$H_{SD}(s)/_{s\to\infty} = O(s^{-2}) \quad (32)$$

$$H_{SD}(s)/_{s=0} = 0, \qquad H_{SD}(s)/_{s\to 0} = O(s) \quad (33)$$

$$H_{SD}(s)_{s=j\omega_2} = -\left(1+\frac{m_u}{m_s}\right), \text{ where}$$

$$\omega_2 = \sqrt{k_t/(m_u+m_s)} \quad (34)$$

$$H_{TD}(s)/_{s\to\infty} = -1 + O(s^{-2}) \quad (35)$$

$$H_{TD}(s)/_{s=0} = 0,$$
$$H_{TD}(s)/_{s\to 0} = -(m_u+m_s)s^2/k_t + O(s^3) \quad (36)$$

Note, that even though it is desirable to prevent amplitudes of the frequency responses $H_{SP}(s)$, $H_{SD}(s)$, and $H_{TD}(s)$ being too large in any frequency domain, a brief analysis of the expressions (29) - (36) enables to find out that the investigated transfer functions must have modulus strictly grater that one at some frequencies what indicates the fact that the road disturbance signal is amplified at these mentioned frequencies.

The same approach can be used to derive limitations for other transfer functions and various choices of the measured outputs.

It has been shown that the limitations always arise in the form of invariant frequency points (for example $\omega_1 = \sqrt{\frac{k_t}{m_u}}$ for $H^1_{zw}(j\omega_1)$, $\omega_2 = \sqrt{\frac{k_t}{m_u+m_s}}$ for $H^2_{zw}(j\omega_2)$ and $\omega_3 = 0$ for $H^3_{zw}(j\omega_3)$) and in the form of restricted rate of decay at frequencies tending to zero and infinity.

As an example, the complete sets of constraints for transfer functions $H^1_{zw}(s)$, $H^2_{zw}(s)$ and $H^3_{zw}(s)$, when suspension deflection and suspension deflection velocity are measured, is as follows [2],[3]:

$H^1_{zw}(s)/_{s\to\infty} = O(s^{-3})$ (infinite frequency constraint)

$H^1_{zw}(s)/_{s\to 0} = 1 + O(s^2)$ (zero frequency constraint)

$H^1_{zw}(j\omega_1) = -\frac{m_u}{m_s}$ for $\omega_1 = \sqrt{\frac{k_t}{m_u}}$

and analogically:

$H^2_{zw}(s)/_{s\to\infty} = -\frac{k_t}{m_u}s^{-2} + O(s^{-3})$ (infinity freq. constraint)

$H^2_{zw}(s)/_{s\to 0} = O(s^2)$ (zero frequency constraint)

$H^2_{zw}(j\omega_2) = -(1+\frac{m_u}{m_s})$ for $\omega_2 = \sqrt{\frac{k_t}{m_u+m_s}}$ and

$H^3_{zw}(s)_{s\to\infty} = -1 + \frac{k_t}{m_u}s^{-2} + O(s^{-3})$(infinity freq. constraint)

$H^3_{zw}(s)/_{s\to 0} = -\frac{(m_u+m_s)}{k_t}s^2 + O(s^4)$ (zero freq. constraint)

$H^3_{zw}(j\omega_3) = 0$ for $\omega_3 = 0$.

It is often assumed that if practical difficulties are neglected, active systems could in principle produce arbitrary ideal behavior. This paper presents the factorization approach that is taken to derive limitations of achievable frequency responses for active vehicle suspension systems in terms of invariant frequency points and restricted rate of decay at high frequencies.

In control law design for active suspension system of vehicles it is demanded to prevent magnitudes of the road and load frequency responses from being too large. There are some frequency points and frequency ranges where the transfer functions have modulus strictly greater than one i.e. where road and load disturbance amplification occur. On the base of the Bode integral it can be shown that the transfer functions must be greater in modulus to at least the same extend that it is less than one, when measured in terms of the area on a Bode magnitude plot [1], [2] [3]. In such a case there is a possibility to shift frequency ranges where disturbance amplification occurs to a "more advantageous place" or to make magnitudes lower spreading the frequency range.

5. Analysis of the Complete Sets of Limitations

In context with transfer functions $H(s)$ of the one-quarter-car model given in Section 1, the generalized Bode integral theorem can be modified as follows [1] :

Theorem 1. Let RH_∞ is a set of rational transfer functions that are stable (their poles lie in the open right half-plane) and proper (the numerator degree of these functions is less than or equal to the denominator degree). Let $H(s)$ belongs to RH_∞ and satisfies $H(s)/_{s\to\infty} = -1 + O(s^{-2})$. Let $\{z_i, i = 1,..,n \quad n \in N\}$ are zeros of $H(s)$ with $Re(z_i) > 0$. Then:

$$\int_0^\infty log|H(j\omega)|\, d\omega = \pi \sum_{i=1}^n Re(z_i) \quad (37)$$

In control law design, it is desirable to prevent amplitudes of the dynamic responses $H^1_{zw}(s)$, $H^2_{zw}(s)$ and $H^3_{zw}(s)$ from being too large.

A brief examination of the results stated in Section 1 shows that the suspension deflection transfer function $H^2_{zw}(s)$ has modulus strictly grater than one for $\omega_2 = \sqrt{\frac{k_t}{m_u+m_s}}$ ($H^2_{zw}(j\omega_2) = -\left(1+\frac{m_u}{m_s}\right)$), i.e. at this frequency an amplification grater than one occurs. This amplification can be made less only and only by

adjusting the ratio of the unsprung and sprung masses. From the result:

$$H_{zw}^{3}(s)/_{s\to\infty} = -1 + \frac{k_t}{m_u} s^{-2} + O(s^{-3}) \quad (38)$$

it is evident, that $|H_{zw}^{3}(j\omega)|$ must tend to one from above as ω tends to ∞ and it turns out that $|H_{zw}^{3}(j\omega)|$cannot be made less than or equal to one at all frequencies. Since the right-hand side of (37) is non-negative then it is not possible for $|H_{zw}^{3}(j\omega)|$ to be less than or equal to one at all frequencies since that would make the left-hand side of the equation (37) negative. It has been shown in [3], that no matter what signals are used for feedback, the tire deflection transfer function must amplify road disturbances at some frequencies. This fact is valid even for full state feedback used in the control loop.

A similar theorem is valid for transfer functions where $H(s)/_{s\to 0} = 1 + O(s^2)$

Theorem 2. Let $H(s)$ belongs to RH_∞ and satisfies$H(s)/_{s\to 0} = 1 + O(s^2)$.Let $\{z_i, i = 1,..,n \quad n \in N\}$ are zeros of $H(s)$ with $Re(z_i) > 0$. Then:

$$\int_0^\infty log|H(j\omega)| \frac{d\omega}{\omega^2} = \pi \sum_{i=1}^{n} \frac{Re(z_i)}{|z_i|^2} \quad (39)$$

Similarly to the consequences of Theorem 3, the result $H_{zw}^{1}(s)/_{s\to 0} = 1 + O(s^2)$ from Section 1 is the case when $|H_{zw}^{1}(j\omega)|$ cannot be less than or equal to one at all frequencies since that would make the left-hand side of (39) negative. This fact is again valid even when full state feedback is introduced in the control loop [3].

In such cases that were mentioned above designers have the only possibility ”to shift” the frequencies where the amplifications occur to ”more advantageous places” or ”to spread” the ranges where amplifications occur making the amplification lower the positive area of the Bode magnitude plot, i.e. the area where $|H(j\omega)|$ is greater than one (is grater to at least the same extent than the negative area where $|H(j\omega)|$ is less than one) by choosing a proper feedback controller. Analogically, similar results can be derived for arbitrarily chosen measurements and load disturbances.

6. Results

Using a simple linear two-degree of freedom car suspension model in Fig.1, it was shown that there are still some limitations to suspension performance even in the fully active state. It has been shown in the paper that there are some frequency points and frequency ranges where the transfer functions have modulus strictly greater than one i.e. where road and load disturbance amplification occurs. On the base of the Bode integral theorems, it has been shown that the transfer functions must be greater in modulus to at least the same extent that it is less than one when measured in terms of the area on a Bode magnitude plot. In such a case there is a possibility to shift frequency ranges where disturbance amplification occurs to a ”more advantageous place” or to make magnitudes lower spreading the frequency range.

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MEMBRANE DISTILLATION USING SOLAR ENERGY – MEMBRANE MODIFICATION

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Abstract: *The desalination is an important technological process applied not only to obtain drinking water, but also for wastewater treatment from e.g. dyes, textile and mining industry. In this process, membrane processes such as reverse osmosis, pervaporation, electrodialysis and membrane distillation are quite commonly used. This work focuses on membrane distillation. The research was carried out in order to produce membranes absorbing solar radiation, to use this energy in the distillation process. Membranes were produced using the phase inversion method from polysulfone polymer at various proportions of ingredients to select the optimal blend composition. The fabricated membranes were investigated to assess wettability, maximum pore size and execute preliminary tests of the membrane distillation process.*

Keywords: WATER DESALINATION, RENEWEBLE ENERGY, MEMBRANE DISTILLATION, POLYSULFONE MEMBRANE, COOPER OXIDE

1. Introduction

According to current global estimations, approximately 2.7 billion people around the world do not have access to drinking water [1]. Prognosis of this situation is getting worse and worse, due to the climate changes and deteriorating quality of the inland waters, mainly due to the environmental pollution. It is estimated that by 2025, even 2/3 of world population may not have access to the drinking water [2]. At the moment, more than 14000 installations desalting sea water are actively working, giving total efficiency of about few billions liters per day. More than half of those type of systems are placed in the area of the Middle East and the Persian Gulf. They working principle is based on conventional electrical power and heating stations.

The use of the conventional fossil fuels for desalting sea water has two main drawbacks: increases costs of purified water as well as has negative influence on natural habitat [3]. Due to the fact that amount of available fossil fuels is constantly decreasing and geographical localization of the areas suffering from drinking water shortage in zones with high solar radiation, the application of the renewable sources of energy in the water desalting and purification process is getting more and more cost-effective.

Desalination of the water, according to the basic definition, is a process in which salty water is separated to fractions of fresh water (do not containing salt) and brine concentrate (fraction of higher salinity) [4]. Generally, desalination processes can be divided into three categories: thermal, membrane, and alternative. The last type includes freezing and ion exchange techniques. Thermal processes can be categorized further, including: multi-stage flash distillation (MSF) [5], multiple-effect distillation (MED) [6], vapour-compression evaporation (VC) [7], cogeneration [8], solar water desalination (SD) [9]. Cogeneration using off-heat from already existing installations is difficult, cause their localization not always cohere with places endangered by lack of access to drinking water.

Solar water desalination process needs large surface areas dedicated to collectors, that inhibits running the process in large scale. Energy consumption in the thermal processes is significantly exceeding reasonable values of the cost-effective methods. Therefore membrane-based techniques are getting more and more popular. Membrane processes belongs to the technology for splitting mixtures or solutions exploiting porous or non-porous membranes.

Water desalination processes are based mostly on following phenomena: reverse osmosis (RO), electrodialysis (ED) and membrane distillation (MD).

Reverse osmosis is a process running under pressure between 10 to 100 bar, exploiting a membrane which is able to filter low-mass compounds, or even ions. Investigations of the RO applied in the sea water desalination have been conducted for over 30 years, leading to very good process optimization and decreasing the energy consumption to the level of 2 kWh/m3. This value is very close to the theoretical energetically demand of 1_kWh/m3. Regardless, well-established technology and fine optimization of the process, RO has its drawbacks, e.g. susceptibility for concentration polarization and fouling from inorganic, organic and biological constituents, what influences permeate stream obtained in the process.

When the transport of cations and anions from solution occurs through semi-permeable ion-exchange membranes this technique is known as electrodialysis. The difference in electric potential is the driving force of this process [10]. This method is not that popular as MD, which in the recent years reached success in the water desalination. In contrary to RO settings, where high pressure on the side of the feed causes the process, the driving force of MD is temperature difference. It is possible to run MD at normal pressure, at the feed temperature below the boiling point. The very important asset of MD is possibility to operate at wide range of salt concentrations, because it has no effect on overall driving force of the process. And also obtained this way water is of the high purity and quality. Additionally, due to the thermal parameters of the process it is feasible to use off-heat or renewable sources of energy [10,11,12].

A direct absorption of the solar energy on the membrane is other alternative and innovative method. First research studies of this type conducted at Rice University in Huston reports on efficiency of the process at the level of 5dm3 of water from 1m2 of membrane within an hour, reaching desalination of 99.5%, when using modified membranes. Even though these results are not outstanding in comparison to other MD technologies gives the path for novel approaches for modifications of the MD processes.

The applied membrane has been modified by thin film coating of PVP containing carbon nanoparticles. This type of modification caused blackening of the membrane and increased absorption of the solar radiation [13].

2. Materials and methods

2.1. Chemicals

Polisulfone (PSU) Mn~22,000 (Sigma Aldrich), Ultrapure water (Milli-Q®,Millipore N,N-dimethylacetamide (DMA, 99.5%, Honeywell), Polyvinylpyrrolidone (PVP) K15 and K30 (Fluka), Copper(II) oxide nanopowder (Sigma Aldrich) were used to membrane preparation.

2.2. Solar Membrane distillation process

A schematic illustration of the experimental equipment is presented in Fig. 1. It consisted of a 3L thermostated feed tank

(stainless steel), linked to membrane module (with polycarbonate window) containing membrane (area: 11 cm2). The pump placed in feed tank allowed the feed (salinity water, temperature 50oC) flowing through the membrane unit with flow velocity of 4mm/s. The process was conducted in air gap membrane distillation configuration (air gap is interposed between the membrane cold surface and a condensation surface) in two series: without and with membrane illuminated by an artificial light source Helios 100 W Neodymium Bulb Daylight Lamp. Luminous flux density on the contactor surface ~70000 lux. The condensation surface was made of a copper plate and cooled by circulated water (temperature 8oC). The distillate samples were collected into a measuring vessel with simultaneous measurement of time.

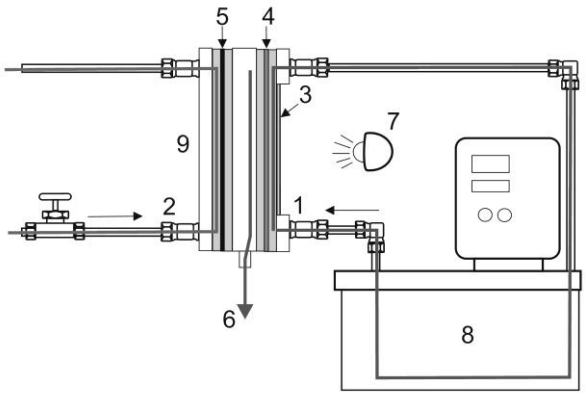

Fig. 1 *Schematic diagram of the laboratory solar membrane distillation setup. 1 – Feed inlet, 2 – cooling water inlet, 3 – polycarbonate window, 4 – membrane, 5 – cooling plate, 6 – distillate outlet, 7 – light source, 8 – feed thermostated tank, 9 – membrane module*

2.3. Membrane preparation

Flat, porous membranes were prepared by the phase inversion method. The, polysulfon was dissolved in DMA to achieve concentration in the range of 18-23%, and PVP was gradually added as blowing agent. The mixture was stirred continuously at 30 °C for 12 h until a transparent solution was obtained. The copper oxide was added to selected solutions to increase the absorption coefficient of light. The detailed composition of the membranes is given in the table 1. In order to carry out the phase inversion process the solution was cast onto a clean glass substrate at room temperature using a stainless steel knife. The knife rod was used to define solution height during casting, the knife height was 240 µm. The substrate was immersed into a ultrapure water bath (temperature 25 °C) in order to carry out subsequent phase inversion process. The resulting membrane was removed from water bath, and immersed into deionized water for 48 h.

Table 1: *Composition of solutions for different membranes*

Membrane	Polysulfone [g]	DMA [g]	PVP 15 [g]	PVP 30 [g]	Copper oxide [g]
1	1,15	5	0,0575	-	-
2	1,15	5	0,115	-	-
3	0,9	5	0,045	-	-
4	0,9	5	0,090	-	-
5	1,15	5	-	0,0575	-
6	1,15	5	-	0,115	-
7	0,9	5	-	0,045	-
8	0,9	5	-	0,090	-
9	1,15	5	0,0575	-	0,115
10	0,9	5	-	0,090	0,090

2.4. Salt concentration

The salt concentration in the collected samples was measured with a universal Elmetron CPC 501 device using a conductometric method and a type CD-2 electrode. The samples of distillate after the process was measured at 20°C using a previously prepared calibration curve.

2.5. Wettability

The contact angle was determined for all prepared membranes using goniometer Surftens-universal (Optik Elektronik Geratechnik). A droplet by volume 2 µl of deionized water was used as the probe. The measurement for each sample was conducted at ten different locations, and average value was reported.

2.6. Distillation flux

The distillation flux was calculated by Eq. (1):

$$J_v = \frac{V}{At} \tag{1}$$

where: V is the volume of the permeate obtained after time t, [m3], A s the area of the membrane [m2] and t is time taken to collect permeate volume V [h].

2.7. Salt rejection

For the purpose of evaluating the desalination performance, the following fundamental formula was used, giving the rejection coefficient (Eq. (2)):

$$R = \left(1 - \frac{c_p}{c_F}\right) \cdot 100\% \tag{2}$$

where: R is rejection coefficient [%], c_P is concentration of salt in the distillate [mg/kg] c_F is concentration of salt in the feed [mg/kg] 8mg/kg (corresponding to the salinity of Baltic Sea)

2.8. Maximum pore size

The bubble point test was used to determine maximum pore size. Maximum pore size was calculated using Eq. (3):

$$D = \frac{4\gamma \cos\theta}{P} \tag{3}$$

where: P [Pa] is the pressure, D [m] diameter of capillary or pore, θ [deg] is the contact angle between the liquid and capillary wall and γ [N/m] is the surface tension of the liquid.

2.9. Overall porosity

The overall membrane porosity was measured by the gravimetric method [14,15]. After the phase inversion, solvent (DMA) was exchanged in the membrane by the deionized water. Samples for overall porosity determination were further immersed in distilled water for another 72 h. Then they were wiped with blotting paper and weighed to determine the wet mass (mw, g). After being dried in vacuum dryer for 24 h at 40 °C, the dry mass of the samples (md, g) was measured. The overall porosity (ε, %) was calculated using Eq. (1).

$$\varepsilon = \frac{\frac{(m_w - m_d)}{\rho_w}}{\frac{(m_w - m_d)}{\rho_w} + \frac{m_d}{\rho_p}} \cdot 100 \tag{4}$$

where ρ_w is the density of water (0.997 g cm^{-3} at 25 °C) and ρ_p is the polymer density (1.24 g cm^{-3} at 25 °C).

3. Results

In Table 2 the results of investigations of the properties of polysulfone membranes produced during study and distillate flux obtained during membrane distillation (feed temperature: 50oC, with and without light) are presented. The resulting membranes were characterized by a low contact angle in the range of 52,2 to 68,3o and pore maximum pore size from 0,13 to 5,52 μm. The overall porosity of the as-prepared PSU membranes was about 90%. It slightly decreased for the membranes with PVP 30 as blowing agent.

Table 2: *Properties of the PSU membrane and comparison of the distillate flux of different membranes*

Membrane number	Wettability	Maximum pore size [μm]	Overall porosity	Distillation flux [dm^3/m^2h]	Salt rejection [%]	Distillation flux with solar energy [dm^3/m^2h]	Salt rejection with solar energy [%[	The fold increase in the light flux
1	67,6	0,17	90,1	9,25	97,78	9,87	99,60	1,07
2	73,8	0,13	88,6	10,00	95,25	11,54	93,24	1,15
3	51,9	0,22	91,4	90,89	6,53	114,62	5,41	1,26
4	56,4	5,52	91,3	269,30	7,59	346,32	8,58	1,29
5	68,3	1,58	89,2	9,87	98,71	10,10	98,87	1,02
6	64,9	1,14	87,1	10,77	98,98	11,58	98,47	1,08
7	66,8	2,64	89,1	28,46	28,38	37,03	15,78	1,30
8	48,0	2,66	89,2	26,93	32,61	35,46	31,55	1,32
9	66,0	2,13	90,5	7,34	92,74	10,21	92,01	1,39
10	52,2	1,10	87,9	19,75	47,19	29,32	30,03	1,48

Only five of the prepared membranes showed the ability to remove salts at the level above 90%, however, for these membranes the distillate flux did not exceed 11 $dm^3/(m^2h)$ for process without additional membrane illumination by an artificial light source. For all membranes, an increase in the distillate flux caused by the light's illuminating of the membrane was observed. The largest fold increase in the distillate flux was observed for the membrane with copper oxide and it is equal to 1,48. The addition of copper oxide increased the coefficient of light absorption.

4. Conclusions

The membrane distillation can solve problem with water demands in regions affected by a shortage of drinking water. Process of membrane desalination can only be carried out at elevated feed temperature, but this require substantial energy from conventional power plants. The research indicates that increasing of the light absorption coefficient of the membrane affects the increase of the distillate flux. The production of innovative membranes with such properties gives the potential possibility of conducting the membrane distillation process in geographical localization areas suffering from drinking water shortage with high solar radiation without the use of energy from conventional sources.

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STUDY OF THE POWER INTERACTION OF A MOVABLE BLOCK COMPOSED OF TWO BORING TOOLS WITH THE ELEMENTS OF THE TECHNOLOGICAL SYSTEM

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Abstract: *In the paper is analyzed the dynamics of a movable block, consist of two boring tool with oppositely positioned cutting inserts, applied as a cutting part of tools for combined machining of deep holes by cutting and surface plastic deformation. Tribo-mechanical and force dependencies were derived, connecting the geometry of the cutting inserts and the friction forces in the contact surfaces of the block with its working capacity.*

Key words: movable block composed of two boring tools, self-basing, cutting forces, friction forces.

1.INTRODUCTION

The movable boring blocks with two cutting tools for boring are most commonly used as cutting parts of tools for the combined machining of deep holes by cutting and surface plastic deformation (SDP) to the surfaces of which there are high quality requirements[1,6,10].

There is a wide variety of tools for the combined machining of holes, and the design of most of them can be represented cinematically as shown in fig. 1. It is composed of three main parts: cutting, deforming and joining.

The cutting part includes movable boring block 1 with oppositely positioned cutting inserts П1 and П2 and holder with guides 2. The deforming part comprises a support cone 4, deforming elements (rollers or balls) 5 which are arranged in a separator 6. The three parts are mounted on a bearing shaft 7 [4,5].

In the course of machining the movable boring block is self-basing in the radial direction as a result of the constant striving to equalize the radial cutting forces acting on each of the cutting inserts. This striving is not affected by whether the plates are located in a plane perpendicular to the axis of rotation or are displaced relative to each other in the axial direction. The last is applied if it is necessary to remove a larger allowance of machining and removal without defect the tool from the machined hole [3,7,10].

In order to analyze the kinematic behavior of movable block with two boring tools in the course of its evenly feed movement, the process of machining the hole is conditionally devided into three periods depending on its behavior in contact with the workpiece [8]: period of initial self-basing, period of an established cutting, period of final self-basing.

The period of initial self-basing starts from the moment when one of the two opposite inserts get in contact with the entrance face of the workpiece and ends at the moment when each of them reaches the cutting depths regulated by the size of the static adjustment of the block, in which will run the second period.

The first period is divided into two stages: the initial self-basing stage without incision and a stage of initial self-basing at incision.

The dynamic behavior of the block during the different periods of its interaction with the workpiece and the holder is similar to the kinematic, but the emerging forces in the contact zones impose additional constraints that ensure its efficiency [1,4].

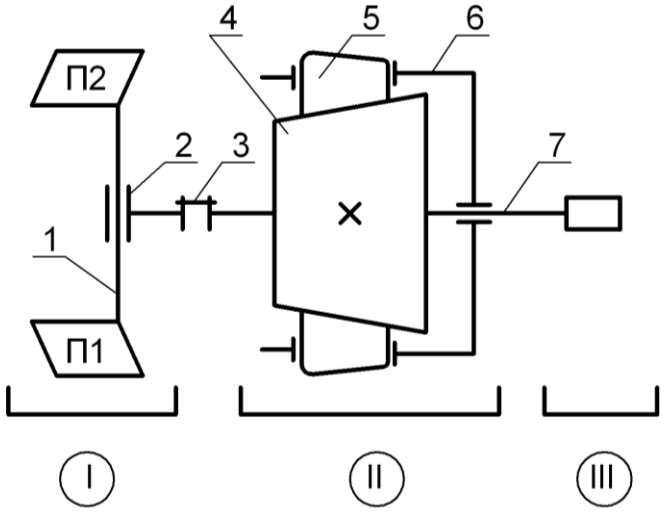

Fig.1. *Kinematic scheme of a tool for combined machining: I – cutting part; II – deforming part; III – joining part*

2.EXPLANATION

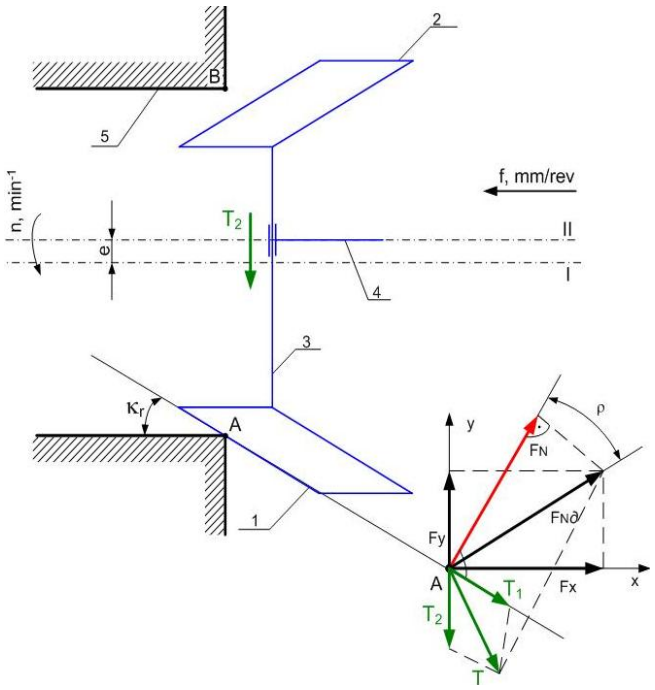

Fig.2 *Scheme of self-basing stage without incision: 1,2– cutting inserts; 3 – guides of a block; 4 – holder; 5 –workpiece*

Fig.2 shows schematically the stage of initial self-basing without incision. It is considered under the condition that *I* is the symmetry axis of the block having an initial displacement *e* relative to the matching axes of symmetry of the hole and the holder with the axis of rotation of the machine *II* [8,10].

Upon contact of one of the cutting edges to the workpiece during a feeding at the point of contact appears normal force F_N directed perpendicular to the cutting edge. Its magnitude depends on the magnitude of the cutting edge angle of the insert and on the friction resistance of the cutting edge with the workpiece and with the guides. As a result of the friction, the actual normal force $F_{N\partial}$ is practically shifted and has a modified value:

$$F_{N\partial} = F_N / \cos\rho, \quad (1)$$

where F_N is normal force to the cutting edge, and ρ - friction angle.

Considering this the friction angle is determined by the dependence:

$$\rho = artg(\mu_1 + \mu_2), \quad (2)$$

where μ_1 is the coefficient of friction between the cutting edge and the workpiece;

μ_2 - the coefficient of friction between the block and its guides.

The projections of the force $F_{N\partial}$ on the both coordinate axes are:

$$F_X = F_{N\partial}.\sin(\kappa_r + \rho), \quad (3)$$

$$F_Y = F_{N\partial}.\cos(\kappa_r + \rho). \quad (4)$$

The ratio of both forces is obtained:

$$\frac{F_X}{F_Y} = tg(\kappa_r + \rho). \quad (5)$$

In the process of self-basing under the action of the radial component F_Y, the movable block moves against which resists the frictional force *T* at the cutting edge and the guides of the block. In order to carry out the relocation, it is necessary to meet the condition:

$$F_Y > T. \quad (6)$$

If this condition is not met, the cutting process will run at work only of one cutting edge, i.e. such as cutting at boring with a fixed tool.

From equation (5) for the radial force is obtained:

$$F_Y = \frac{F_X}{tg(\kappa_r + \rho)} \quad (7)$$

The friction force *T* is determined by summing the friction forces T_1 and T_2 respectively by normal force F_N and its axial component F_X:

$$T = \mu_1.F_N.\cos(90 - \kappa_r) + \mu_2.F_X. \quad (8)$$

Considering the homogeneity of the contacting materials in this case it can be assumed that $\mu_1 = \mu_2 = \mu$ whereupon $\rho = arctg2\mu$ and

$$T = \mu.(F_N.\sin\kappa_r + F_X). \quad (9)$$

According to fig.2

$$F_N = F_{N\partial}.\cos\rho = \frac{F_X.\cos\rho}{\sin(\kappa_r + \rho)}. \quad (10)$$

After the substitution of (7) and (10) in (6) an expression is defined, determining the self-basing condition of the tool before the start of chipformation, when the workpiece contacts with only one cutting edge:

$$\frac{\cos(\kappa_r + \rho)}{\cos\rho.\sin\kappa_r + \sin(\kappa_r + \rho)} > \mu \quad (11)$$

Based on the dependence (11), can be determined the limit values of the cutting edge angle κ_r under different friction conditions.

The incision stage ends when the elements of the cut layer reach their maximum dimensions. From this point begins the period of established cutting characterized in that the cut layer theoretically has to be divided between the two cutting parts of the boring block whereupon to achieve fully equilibrium radial cutting forces [9].

Despite the theoretically uniform cutting depths, in real conditions the ideal equilibrium state is unattainable due to: the resistance of the friction forces against the radial shift of the boring block; the deviation of the axis of symmetry of the machined hole relative to the axis of rotation of the machine and the position of the block relative to the both axes.

The shifting in radial direction is realized under force $\Delta F_P = |F_{PA} - F_{PB}|$ and continues until the condition is met $\Delta F_P > T$, where *T* is the friction force between the guides and the block.

At $\Delta F_P \le T$ the last is stationary relative to the holder, corresponding to roughly equal depths, respectively the cutting forces for the both tools.

For establishing the force dependencies resulting from the mismatch of the axes in fig.3 is made geometric analysis of the forces acting on the boring block [2].

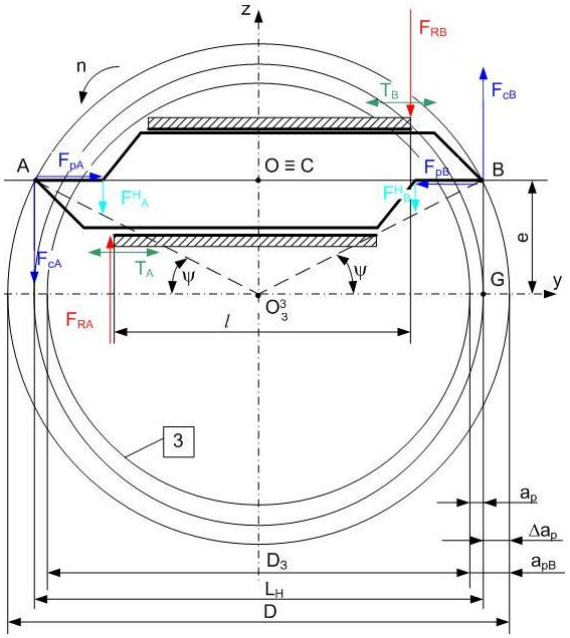

Fig.3. *Scheme of the power load of a movable boring block at deviation relative to the axis of rotation*

The total force of the resistance of friction between the block and guide it will be:

$$T = T_A + T_B + T_X . \quad (12)$$

Friction forces can be obtained through the dependencies:

$$T_A = F_{RA}.\mu;$$
$$T_B = F_{RB}.\mu; \quad (13)$$
$$T_X = \left(F_{fA} + F_{fB}\right).\mu,$$

where μ is the coefficient of friction between the block and the guides.

For defining F_{RA} and F_{RB} - the pair of forces balancing the torque of action of tangential cutting forces and transverse forces as well, the *Z*-axis equilibrium conditions and the torques relative to the center *O* are used.

$$\sum Z_i = 0; F_{CA} + F_A^H - F_{RA} + F_B^H + F_{RB} - F_{CB} = 0$$
$$\sum M_{Oi} = 0; \left[\left(F_{CA} + F_A^H\right) + \left(F_{CB} - F_B^H\right)\right]\frac{L_H}{2} - \frac{l}{2}\left(F_{RA} + F_{RB}\right) = 0, \quad (14)$$

where *l* is the length of the guides

In fact, due to the small value of the clearance between the block and the holder, the load on it under the action of the main cutting forces has a triangular distribution, whereby F_{RA} and F_{RB} are its equivalent forces. In this case, the distance between them is less than l, but it can hardly be determined. For this reason, the full length of the guides is selected for the moment arm of the pair of forces, resulting in some decrease in the calculated value of the friction force.

The force balance is not considered for axial displacement of the plates because its small value makes its influence on the friction force insignificant.

According to the theory of equilibration of the cutting forces:

$$F_{CA} = F_{CB} = F_C; F_{PA} = F_{PB} = F_P; F_A^H = F_B^H = F^H \quad (15)$$

As a result of solving of the system (14) it is obtained:

$$F_{RA} = \frac{L_H}{l}F_C + \frac{2e}{L_H}F_P;\ F_{RB} = \frac{L_H}{l}F_C - \frac{2e}{L_H}F_P . \quad (16)$$

After replacing of (16) and (13) in (12) and taking into account that $F_{fA} = F_{fB} = F_f$, the expression for determining the total frictional force acquires the type:

$$T = 2\mu\left(\frac{L_H}{l}F_C + F_f\right). \quad (17)$$

Dependance (17) enables to establish that the force of friction in the guides between block and holder depends only on the tangential and axial components of the cutting force and the length of the guides of the holder but the tangential component's influence is stronger.

3.CONCLUSIONS

1. The phase of self-basing without incision of movable boring block with rectilinear cutting edges depends on cutting edge angle of the cutting inserts, the resistance of friction in the guides of the block and its contact with the workpiece. If the restrictive condition (11) is not complied with, the phase may not consist whereby the cutting part of the tool will bore the hole at stationary block disposed asymmetrically with relative to the axis of the hole of the workpiece which will obtain an unregulated expansion.
2. From the exploitation point of view, it is crucial for dimension forming of the cylindrical holes during the period of established cutting. In self-basing of the movable boring block by translation it is realized only by the action of the radial cutting forces at the both cutting inserts and is influenced by the sensitivity of the block to the difference between them arising for different reasons. There is a threshold of sensitivity to this difference, which is determined by the force of friction in the guides of the block.

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