ISSN 2224-5294

ҚАЗАҚСТАН РЕСПУБЛИКАСЫ
ҰЛТТЫҚ ҒЫЛЫМ АКАДЕМИЯСЫНЫҢ

Абай атындағы Қазақ ұлттық педагогикалық университетінің

Х А Б А Р Л А Р Ы

ИЗВЕСТИЯ

НАЦИОНАЛЬНОЙ АКАДЕМИИ НАУК
РЕСПУБЛИКИ КАЗАХСТАН
Казахский национальный
педагогический университет им. Абая

N E W S

OF THE NATIONAL ACADEMY OF CIENCES
OF THE REPUBLIC OF KAZAKHSTAN
Abay kazakh national
pedagogical university

SERIES
OF SOCIAL AND HUMAN SCIENCES

2 (324)

MARCH - APRIL 2019

PUBLISHED SINCE JANUARY 1962

PUBLISHED 6 TIMES A YEAR

ALMATY, NAS RK

«Қазақстан Республикасы Ұлттық ғылым академиясының Хабарлары. Қоғамдық және гуманитарлық ғылымдар сериясы». ISSN 2224-5294

Меншіктенуші: «Қазақстан Республикасының Ұлттық ғылым академиясы» РҚБ (Алматы қ.)
Қазақстан республикасының Мәдениет пен ақпарат министрлігінің Ақпарат және мұрағат комитетінде 30.04.2010 ж. берілген **№ 10894-Ж** мерзімдік басылым тіркеуіне қойылу туралы куәлік

Мерзімділігі: жылына 6 рет.
Тиражы: 500 дана.

Редакцияның мекенжайы: 050010, Алматы қ., Шевченко көш., 28, 219 бөл., 220, тел.: 272-13-19, 272-13-18,
http://soc-human.kz/index.php/en/arhiv

Типографияның мекенжайы: «Аруна» ЖК, Алматы қ., Муратбаева көш., 75.

Известия Национальной академии наук Республики Казахстан. Серия общественных и гумани-тарных наук. ISSN 2224-5294
Собственник: РОО «Национальная академия наук Республики Казахстан» (г. Алматы)
Свидетельство о постановке на учет периодического печатного издания в Комитете информации и архивов Министерства культуры и информации Республики Казахстан **№ 10894-Ж**, выданное 30.04.2010 г.

Периодичность 6 раз в год
Тираж: 500 экземпляров

Адрес редакции: 050010, г. Алматы, ул. Шевченко, 28, ком. 219, 220, тел. 272-13-19, 272-13-18,
http://soc-human.kz/index.php/en/arhiv

Адрес типографии: ИП «Аруна», г. Алматы, ул. Муратбаева, 75

News of the National Academy of Sciences of the Republic of Kazakhstan. Series of Social and Humanities.
ISSN 2224-5294
Owner: RPA "National Academy of Sciences of the Republic of Kazakhstan" (Almaty)
The certificate of registration of a periodic printed publication in the Committee of information and archives of the Ministry of culture and information of the Republic of Kazakhstan **N 10894-Ж**, issued 30.04.2010

Periodicity: 6 times a year
Circulation: 500 copies

Editorial address: 28, Shevchenko str., of. 219, 220, Almaty, 050010, tel. 272-13-19, 272-13-18,
http://soc-human.kz/index.php/en/arhiv

Address of printing house: ST "Aruna", 75, Muratbayev str, Almaty

N E W S
OF THE NATIONAL ACADEMY OF SCIENCES OF THE REPUBLIC OF KAZAKHSTAN
SERIES OF SOCIAL AND HUMAN SCIENCES
ISSN 2224-5294 **https://doi.org/10.32014/2019.2224-5294.56**
Volume 2, Number 324 (2019), 113 – 120

UDC 330.1

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ECONOMIC EFFICIENCY OF APPLICATION OF ADDITIVE TECHNOLOGIES (3D PRINTING) IN THE MANUFACTURING INDUSTRY

Abstract: The aim of the study is that in the conditions of global development, additive technologies are able to return some of the production of high-tech products, concentrating them in developed countries. The need for technology development will cause a qualitative leap in conducting research of various kinds aimed at optimizing the operating modes of equipment, expanding the range of materials used, expanding the technological capabilities of installations. The use of technologies for additive manufacturing and additive technologies in Kazakhstan is obvious, as it can help Kazakhstan enterprises to optimize their non-core activities, for example, metalworking and electroplating plants and reduce storage costs.

Domestic science and industry will have to invest a lot of effort in order to make up for lost time and to meet the needs of their own market with both the installations of additive production and the availability of raw materials.

The methodological basis of the article is a systematic approach to the study and description of the relationship of the operational properties of the part with the technological conditions of three-dimensional printing.

Keywords: additive technologies; three-dimensional printing; technological innovation.

Introduction – The last few years in the world are increasingly saying that 3D printing will soon enter all areas of our life. It will be possible to print everything on a printer - from food to details of fighters and donor organs. Is this true, and how does this sphere develop in our country? 3D printers, which were talked about only a few years ago and about whose device most people have a rather vague idea, can in the near future completely transform the industrial production scheme on the planet.

The scientific novelty and practical significance of the study of additive technologies for Kazakhstan are obvious. First of all, this is the creation of a new field of technological knowledge of industrial production. In addition to the economic efficiency of the introduction of additive technologies in production, there is a high social significance.

Additive technology is the process of combining material to create an object from data (model), usually layer by layer, in contrast to “subtracting” production technologies. Under the subtractive technology means the machining - removal ("subtraction") of the material from the array of the work piece. In turn, 3D printing is a colloquial name for additive technologies that are part of a new type of production [1].

Research background - According to Vdovin R.A. and Smelov V.G. in their publications, Additive Fabrication (AF) or Additive Manufacturing (AM) means additive that is, obtained by adding. This technology is based on a layer-by-layer extension of the model obtained by three-dimensional digital modeling or scanning. In past years, the term rapid prototyping (Rapid Prototyping) or RP-technology was used more often [2].

According to M.A. Zlenko, additive technologies today are a rapidly developing industry of industrial production. The market of additive technologies (hereinafter referred to as AP) includes the

implementation of AP installations, the production of models or parts to order or for their own needs, after-sales service of installations, software development, training of specialists and operators, advertising and consulting [3].

In accordance with the research of foreign accounting Attaran M., the domestic market of additive technologies remains underdeveloped, but is gaining momentum. Experience in the development and implementation of metal-printing technologies have individual domestic companies, educational centers. Table 1 shows the industries that most fully mastered additive technologies [4].

Table - 1 Industries applying technology additive technologies

Industry	Applications	Benefits
Aerospace	Prototyping. Production of components for aircraft, launch vehicles and satellites. Weight reduction products.	Production of components for aircraft, launch vehicles and satellites. Weight reduction products. Reducing the cost of production of complex functional products. Local production at the place of demand with no restrictions on delivery. Reduced production time leads to a reduction in the required stocks of raw materials. Optimization of structures (weight reduction, reduction in the number of modular elements).
Automotive	Prototyping. Manufacture of products. Reducing the mass of cars. Cooling system for prototypes operating in particularly difficult conditions.	Optimization of product design. Accelerating the entry of new products into the market. Reduced repair costs. Stock reduction. Improving the quality of products.
Traumatology Surgery Rehabilitation	Implant manufacturing (hearing aids, prostheses). Reconstruction of the bones. Hip joints. Skull implants. Maxillary implants.	Reduced time and cost of operations. Reducing the risks of post-operative complications. Reduced production time. Optimization of implant design for anatomical features.
Dentistry	Dentures and crowns, orthodontic appliances	Reduced production time Anatomical optimization of products
Note - compiled by authors according to the source [4]		

In the context of global development, additive technologies are able to return some of the production of high-tech products, concentrating them in developed countries.

Publishing his scientific articles about the possibilities of the development of additive technologies Yurasev N.I. notes about the need to develop technologies in this area, which will cause a qualitative leap in conducting research of various kinds, aimed at optimizing the operating modes of the equipment, expanding the range of materials used, expanding the technological capabilities of the facilities. The motivations of countries to develop new production technologies, however, are different:

- for the USA, it is the need to maintain world leadership;
- for the countries of Western Europe, this is the preservation of leadership positions in a number of segments in high-tech markets in the conditions of active development of production technologies in the USA, China and Japan.
- for China, this is the development of a new industry with account of its reliance on its own strength [5].

Thus, an important factor contributing to the process of updating the industrialization of developed economies is the development of new production technologies, allowing them to switch to new business models based on product customization.

For Kazakhstan's science and industry, it will be necessary to invest a lot of effort in order to make up for lost time and to meet the needs of its own market both with the installations of additive production and with the availability of the raw material base.

Results of research – The analysis shows that the global market for additive technologies has grown tenfold from 2012 to 2017. 3D printing technologies, although they appeared in the 1980s, turned out to be in demand only in recent years. According to the data of The Boston Consulting Group (BCG) published in 2018, in 2015 the volume of the global 3D printing market was estimated at $ 5 billion, and by 2021 the market promises to grow more than threefold. If, by 2035, 3D printing is introduced at only 1.5% of production capacity, the market volume will already exceed $ 350 billion, while about half of the entire

market will fall on just three sectors: the automotive and aerospace industries, as well as health care, in particular, dentistry [6].

The report of Wohlers Report (2012) states an expert: “The AM-industry market still contains a huge untapped potential, especially in the production of consumer goods and products with rapidly changing designs. Companies spend 5–10% on design testing in prototypes, while the remaining 90–95% spend on the main production of goods. It is for this reason that so many companies want to occupy this market segment. Real money is not in design and not in prototypes, real money is in production. Therefore, manufacturers of AM-systems and service firms are increasingly offering solutions for the production of final products. However, this market is rather complicated for AM technologies in comparison with the market of models and prototypes [1].

Plans for the introduction of 3D printing are developed in Kazakhstan. The development of additive manufacturing technology is indicated by one of the elements of the “Industry 4.0” concept, the need for which has been repeatedly pointed out by the head of state. In addition, as noted in the state Program of Industrial Innovation Development of Kazakhstan for 2015–2019, “within the framework of the autonomous cluster fund Park of Innovative Technologies, until 2019, it is planned to create five centers for the development of technologies (competencies) in the areas of Smart Industry Mining and Metallurgical Complex, “New materials and additive technologies”, “Smart environment”, “Financial technologies”, “New energy and clean technologies”.

An urgent task for Kazakhstan is to find its niche in this market in the coming years and integrate itself into the global chain of suppliers of innovative materials.

The competitive environment is quite conducive to such ambitions, given the country's security with all kinds of necessary raw materials: titanium, aluminum, vanadium, etc. [7]. Breakthrough technology centers in key sectors of the economy are created by the national class fund with the support of the Government in the framework of the 63rd step of the Nation Plan [8]. The partners of the centers are the leading transnational corporations, which as investments compensate the centers for their creation at least 50% of all costs.

As A.N. Chemodurov notes in his scientific publications, of course, the advantages of additive technologies are as follows:

1) elimination of the conflict of the design technologist, since both functions can be performed by one specialist;

2) the possibility of manufacturing products of complex geometric configuration, incl. with internal channels and cavities, with a large surface area, small volume;

3) no need to manufacture tooling equipment and molds;

4) minimizing the loss of material and industrial waste;

5) reducing the time of supply of raw materials, reducing the volume of the warehouse;

6) expediency in individual or small-scale production;

7) reduction of component parts of the created units and assemblies;

8) reducing the number of technological operations, automating the process, reducing labor intensity and production time [9].

In general, in the world of science there are two groups of additive technologies: Bed Deposition and Direct Deposition, which are used by different companies. The strongest position is taken by 3D Systems (more than 1,000 patents), which over the past few years has bought more than 20 firms working in the field of the production of 3D printers, software products, materials, and also in the provision of services [10]. Other leading manufacturers of 3D equipment are Stratasys (506 patents), Z Corp (bought by 3D Systems, 175 patents), Voxeljet (106 patents) [11].

Key companies in the AM industry: 3D Systems Corporation (U. S.), 3T RPD (U. K.), Arcam AB (Sweden), Biomedical Modeling, Inc. (U. S.), Envisiontec GmbH (Germany), EOS GmbH Electro Optical Systems (Germany), Fcubic AB (Sweden), GPI Prototype and Manufacturing Services, Inc. (U. S.), Greatbatch, Inc. (U. S.), Layerwise NV (Belgium), Limacorporate SPA (Italy), Materialise NV (Belgium), Medical Modeling, Inc. (U. S.).

According to a survey of 1000 global industrial companies conducted by Sculpteo, more than 40% of companies already use 3D printing for manufacturing products in 2018 (compared to 22% in 2017), while in the aerospace sector, the greatest use (more than 60% of companies use AP in production) (Table 2) [12].

Table 2 – Purposes of application of 3D printing of industrial companies in the world, comparison of 2017 and 2018

Purposes of application	2017	2018
Prototyping	34%	55%
Production	22%	43%
Concept confirmation	23%	41%
Marketing samples	10%	18%
Art	8%	16%
Education	7%	16%
Hobby	5%	10%
Note - compiled by authors according to source [12]		

The pioneers of the market were the USA, Japan, the countries of Western Europe, including Germany, Great Britain, France and a number of other countries. Each of them has its own established leaders - manufacturers of 3D printers. South Korea, Israel and China, which, with its speed of mastering new technologies, is a source of concern for the traditional leader of high technology trends in the world - the United States - are showing significant activity.

More than 600 patents issued in the field of 3D printing since 1996, more than 50 methods (processes) of printing have been patented by manufacturers of 3D printers, more than 100 patents are issued per year to companies in different industries (industrial leaders patent their own solutions and developments) (Table 3) [12].

Table 3 – The number of patents granted in the field of 3D printing for the period from 2011-2017

Years	2011	2012	2013	2014	2015	2016	2017
Total patents granted (cumulative)	227	247	273	318	336	545	646
Including by year:	40	20	26	45	18	209	101
Printers \ technology	2	1	1	1	0	10	6
Materials	2	1	1	1	1	4	3
Software	2	2	2	3	1	10	5
Aviation	6	2	4	7	3	23	12
Architecture	4	3	2	5	2	21	9
Electronics manufacturing	6	2	2	5	2	29	17
Industry, equipment manufacturing	4	3	4	4	2	23	10
Medicine / Dentistry	6	4	5	10	4	6	16
Automotive industry	4	2	3	6	2	23	12
Others	4	1	3	3	1	19	10
Note - compiled by authors according to source [12]							

The choice of technology - material - a 3D printer is a typical engineering problem in terms of the lack of an unambiguously correct solution. Each individual print order requires detailed consideration (determination of feasibility, possible improvement of characteristics, economic effect). Therefore, it is possible to designate some selection criteria, but it is difficult to unambiguously determine the correct sequence without having your own (or partner) system with the developed selection algorithms, since each case is unique and requires taking into account nuances (matching printing parameters with the required part properties).

Kazakhstan and foreign experts characterize the current development of the Kazakhstan market of additive technologies as a stage of formation in comparison with the world and generally matured to a low level.

So, in September 2017, joining Astana in the framework of the XI Eurasian Forum KAZENERGY, it was noted that, for example, a number of projects on digitalization and robotization of production are being implemented in Kazatomprom. “A digital mine is the very basis that will serve for the introduction of a variety of systems in our production, which, in essence, are Industry 4.0. These are additive technologies, augmented reality, big data and much more. The project has already passed the first pilot stage in the Kazatomprom SaUran enterprise. From the beginning of the implementation of the Digital Mine project, a number of effects have been obtained, in particular:

- the time of equipment diagnosis was reduced from 14 days to two;

- the time of reduced well productivity decreased threefold, in addition, the potential for reducing electricity consumption by 10% was revealed;

- reduced time for reporting.

According to Rustem Sundetov, director of 3D Lab, at least two domestic construction companies in Kazakhstan have 3D printers whose capacity is enough to print a small bath (for comparison, we note that the devices available to the two construction companies from Russia per day can print an apartment with an area of 39 "squares"). Speaking of 3D technologies as the third industrial revolution, the Kazakh expert notes, we should not forget that these developments, with all their progressiveness, can significantly reduce the cost of the process, but they cannot replace serial production on the conveyor.

The most sophisticated and modern 3D printers of German production are in service with the Kazakhstan Garysh Sapary company. “One of the manufacturers of ice cream using 3D-printing produced a form for the production of sweet ice in the form of the hotel“ Kazakhstan ”. The technique of 3D printing by photopolymers is actively used by jewelers and dentists. ” Kazakhstani doctors generally successfully master the new technology, thereby confirming global forecasts that healthcare will become one of the leading sectors in the development of 3D. Before surgeries on complex fractures, young surgeons print fragments of bone on a 3D printer, guided by x-ray data, and before reopening, they rehearse options that are less traumatic for the patient.

The whole process of additive manufacturing consists of the following steps:

- a 3D model of the part is being developed using volumetric modeling software;

- the volume computer model is converted into the standard STL format, loaded into the memory of the AP installation;

- before installation, the installation software cuts a virtual model into layers of the required thickness (each manufacturer’s cutting algorithms are based on their own software algorithms and patented);

- then a layer-by-layer process of growing products based on the data takes place (the “hard” sections of the section are processed).

According to the research of additive technologies in the industrial production of new products in Kazakhstan, according to R. Muhamadeeva and Sharipova A.M., can be held on the basis of the results of 3D Print Conference, held in Kazakhstan. All ongoing activities are focused on businessmen and entrepreneurs of Kazakhstan [13]. 3D printing and scanning are recognized as one of the most promising technology directions. Observations of speeches at conferences, comparison of statistical data on the results of sales of three-dimensional equipment, led to the conclusion that for the introduction and development of new technology requires competence, knowledge, skills and abilities [14].

Thus, the development of additive manufacturing systems can significantly reduce the cost and time of manufacture of complex products, and the expansion of the range of alloys ensures the production of parts with improved characteristics. The use of additive manufacturing technologies would help Kazakhstani enterprises to optimize non-core activities in metalworking and electroplating workshops, and reduce storage costs. The availability of 3D printing services is very important, given that many mining and manufacturing assets are far from settlements. After all, 3D printers capable of printing spare parts, components for equipment and even residential premises are already working today.

Conclusions - New technologies are traditionally introduced into high-tech production areas at low rates, which lead to a strong gap between the demand for an inexpensive, fast product supply and the supply chain characteristic of expensive products with a long life cycle. The experience of Western countries shows that manufacturers of high-tech products will experience increasing pressure from state and private customers in the area of compliance with the concept of e-commerce for product sales. The development of additive production systems can significantly reduce the cost and time of manufacture of complex products, and the expansion of the range of alloys provides for the production of parts with improved characteristics. As a result, some manufacturers began to actively implement these technologies in existing production lines. This behavior is evidence of a high innovation culture. For the rest of the areas of AT need to justify their use, the development of recognition of production processes, changes in design principles.

The introduction of additive technologies and production in the domestic industry, as noted I.Smurov, is in its infancy. Today, Kazakhstan is actively working on the development of additive technologies —

competence centers are being formed and national standards for the segment are being prepared [15]. For companies that want to test the capabilities of 3D-printing in the regions of Kazakhstan, several Competence Centers for additive technologies and prototyping have been created. Such organizations provide their additive equipment for use. The service is suitable for those who need to carry out research and development, produce a unique product, check the capabilities of their technological prototype.

An analysis by J'son & Partners Consulting consultants showed that:

- The 3D printing market is at the very beginning of the rise, printing experiments in various industries, various product ranges, product redesign;
- software, materials, equipment, processes are being intensively improved.

3D printing confidently takes its place in almost all sectors of the real sector of the economy, put into commercial operation, companies continue to expand the range of printed products.

The use of additive technologies in production, marketing, design, visualization for customers and company management is expanding every year. World industrial leaders and experts predict that:

- 2/3 of industrial leaders are already using AP in production processes;
- by 2030, 2/3 of all manufactured products in the world will be produced with printed components;
- by 2030-2050 In a number of manufacturing industries, 3D printing will allow printing of fully finished products [16].

Although prototyping remains a large segment of AP (as historically established first use of AP), the demand for AP in other segments, including the production of functional parts, is growing at the highest rates.

Therefore, the key to control, understanding and leadership in all industry technologies of the future is the accumulation of knowledge about materials, processes and equipment at their own experimental facilities, with maximum computer automation, inter-sectoral coordination and maximum involvement of state support.

Rapid prototyping allows you to make a preliminary assessment of ergonomics, collection and correct layout solutions without the use of expensive tooling. 3D printing of prototypes for R & D, as a rule, shortens the period of each iteration of prototyping from several weeks to several days, so 3D printing gives:

- the ability to significantly ease the weight of parts in production;
- geometric freedom of design allows to achieve the same functional properties of the part, as in traditional production, but at lower costs of the material;
- saving material and facilitating the weight of the product is provided by topological optimization of the product design (when the consumption of raw materials is optimal with given technical characteristics) and the use of lattice, mesh, honeycomb structures instead of a single body;
- reduced the number of production processes and data processing systems.
- allow you to produce complex products autonomously, which is very valuable for the mining industry, aerospace projects and defense.

In their publications Shekhovtsov A.A. about additive technologies as a way to implement the concept of lean manufacturing, notes that the possibility of high-quality development and introduction into production, and most importantly, in the educational process of new additive technologies will help speed up the industrial-innovative development of Kazakhstan and allow young professionals to feel more confident on the international market [17].

The main advantages of additive technology:

- reducing the duration of the technical preparation of the production of new products by 2-4 times;
- reducing the cost of production, especially in small-scale or single production by 2-3 times;
- a significant increase in production flexibility;
- increase the competitiveness of production;
- through the use of computer technology, integration with computer-aided design systems;
- automated quality control of the products obtained;
- visualization of new products and the use of prototypes in the educational process [18].

Investment activity is an important condition for the economic growth of any state in the modern world. Kazakhstan constitute no exception; therefore, its investment attractiveness expansion is one of the main priorities for development. In light of the crisis phenomena in the global economy, competition

between the countries has intensified to attract the investment. Therefore, to ensure the structural transformation of the economy and in terms of limited domestic sources of funds, the development and implementation of new investment policy oriented to the high rates of economic growth and economy efficiency improvement is of prime importance [19].

In general, it can be noted that government support for small and medium-sized enterprises in the Republic of Kazakhstan is multilevel: government support programs for various areas of SMEs activity are being implemented; measures are being taken to reduce the tax burden; legalization of property and assets is conducted; a set of measures to facilitate access to credit resources is being implemented; administrative procedures and permits are simplified; regional centers for supporting small and mediumsized enterprises are organized in both cities and rural areas [20].

According to strategic consultants J'son & Partners Consulting, for Kazakhstan the development of its competencies 3D printing solves a whole range of actual strategic tasks - this is the development of high-tech competencies, import substitution, the development of domestic products, the "landing" of value added in Kazakhstan and increasing labor productivity in various industries.

Thus, we would like to note that the main task of introducing additive production is to increase its economic efficiency indicators and eliminate the shortcomings of traditional production methods, expressed in overproduction and losses due to the presence of excess stocks, time spent on equipment downtime, the presence of extra long production chains, high transport costs.

УДК 334.7

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ӨҢДЕУ ӨНЕРКӘСІБІНДЕ АДДИТИВТІ ТЕХНОЛОГИЯЛАРДЫ ҚОЛДАНУДЫҢ ЭКОНОМИКАЛЫҚ ТИІМДІЛІГІ (3D - БАСПА)

Аннотация. Зерттеудің мақсаты жаһандық даму жағдайында аддитивті технологиялар жоғары технологиялық өнімнің кейбір өндірістерін дамыған елдерге шоғырландырып, қайтаруға қабілетті. Технологияларды дамыту қажеттілігі жабдықтың жұмыс режимін оңтайландыруға, қолданылатын материалдардың номенклатурасын кеңейтуге, Қондырғылардың технологиялық мүмкіндіктерін кеңейтуге бағытталған түрлі зерттеулер жүргізуде сапалы секіруді тудырады. Қазақстанда аддитивті өндіріс технологиялары мен аддитивті технологияларды қолдану айқын, өйткені бұл қазақстандық кәсіпорындарға өзінің бейінсіз қызметін оңтайландыруға, мысалы, металл өңдеу және гальваникалық цехтар мен қойма шығындарын қысқартуға көмектесе алады.

Отандық ғылым мен өнеркәсіпке жіберілген уақытты арттырып, өз нарығының қажеттілігін аддитивті өндіріс қондырғыларымен де, шикізат базасының болуымен де қамтамасыз ету үшін көп күш жұмсауға тура келеді.

Мақаланың әдіснамалық негізі үш өлшемді баспаның технологиялық жағдайларымен бөлшектің пайдалану қасиеттерінің өзара байланысын зерттеу мен сипаттаудың жүйелі тәсілі болып табылады.

Түйін сөздер: аддитивті технологиялар; үш өлшемді баспа; технологиялық инновациялар.

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ЭКОНОМИЧЕСКАЯ ЭФФЕКТИВНОСТЬ ПРИМЕНЕНИЯ АДДИТИВНЫХ ТЕХНОЛОГИЙ (3D - ПЕЧАТЬ) В ОБРАБАТЫВАЮЩЕЙ ПРОМЫШЛЕННОСТИ

Аннотация. Целью исследования является то, что в условиях глобального развития, аддитивные технологии способны вернуть некоторые производства высокотехнологичной продукции, сконцентрировав

их в развитых странах. Необходимость развития технологий вызовет качественный скачок в проведении исследований различного рода, направленных на оптимизацию режимов работы оборудования, расширению номенклатуры применяемых материалов, расширению технологических возможностей установок. Применение технологий аддитивного производства и аддитивных технологий в Казахстане очевидны, так как это может помочь казахстанским предприятиям оптимизировать свою непрофильную деятельность, например, металлообрабатывающие и гальванические цеха и сокращать складские расходы.

Отечественной же науке и промышленности придется вложить немало усилий для того, что наверстать упущенное время и обеспечить потребности собственного рынка как установками аддитивного производства, так и наличием сырьевой базы.

Методологической основой статьи является системный подход к изучению и описанию взаимосвязей эксплуатационных свойств детали с технологическими условиями трехмерной печати.

Ключевые слова: аддитивные технологии; трехмерная печать; технологические инновации.

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Редакторы *М.С. Ахметова, Т.А. Апендиев, Д.С. Аленов*
Верстка на компьютере *А.М. Кульгинбаевой*

Подписано в печать 20.04.2019
Формат 60x881/8. Бумага офсетная. Печать – ризограф.
19,5 п.л. Тираж 500. Заказ 2.