Research of trends in the development of laser additive manufacturing in the Russian Federation on the basis of patent information

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Abstract. The article presents the results of the analysis of patent documentation on laser additive manufacturing registered in the territory of the Russian Federation. As a result of the research, the dynamics of patent activity is determined, the top patent holders, the leading countries in the considered technological field are identified, the top of inventors is compiled, the main technological segments for application of patented solutions from the field of laser additive manufacturing are identified.

1. Introduction

Innovations are one of the most important factors for the effective functioning of the market economy. Innovations cause an increase in the competitiveness of the company, it becomes able to develop new sales markets and capture market niches. It contributes to the creation of favorable conditions for investment [1]. The innovative development of the organization allows it to flexibly respond to customer requests, make timely changes in its activities, and increase competitive advantages in the long term [2]. Every organization that carries out its activities in the field of breakthrough technologies needs to choose the optimal way and method of effectively spending the resources available to it for doing business and making a profit [3]. One of the key technologies among such technologies is laser additive manufacturing [4]. In this regard, the task of analyzing and justifying the priority direction of the organization's innovation activity, taking into account the current trends [5] in the market of laser additive manufacturing, is relevant.

The goal of the research was to form a scientific and economic foundation for building development and protection strategies for creating new technical solutions in laser additive manufacturing.

2. Materials and methods of research

The commercial patent database of Questel Orbit was used as a source of information [6]. The method of cyclic search of patent documentation on the original query and further modification of the query depending on the results obtained after their analysis was used. Various terms and queries were
combined during the search. Logical combination of terms, search by phrase, setting contextual proximity, methods of truncation and substitution were applied. The found patent documents were systematized and grouped into families for the convenience of their analysis. In the future, the research of these families was carried out in relation to the field of laser additive manufacturing in the territory of the Russian Federation. The dynamics of patent activity; the use of technologies in various industries; the distribution of applicants by country of filing the first application; the distribution of patents by applicants were selected as indicators for the statistical analysis of the documents found. The obtained statistical data were presented in the form of tables and diagrams.

3. Results and discussion

The documentation was searched by the characteristic keywords and the corresponding categories of the IPC. 983 patent families were identified (a group of patent documents, each with at least 1 publication of a technical solution in each family and the presence of a document registered by the Federal Service for Intellectual Property (Rospatent) in this group, even if it is not a priority in terms of time). The sample frame was organized in such a way that it included only valid or pending patent documents and the application filing date should not be earlier than 01.01.2000 because a large number of documents were found. This period allowed us to track solutions that coincide with or are younger than the life of the patent for the invention of 20 years at the beginning of this year. The analysis of the patent activity of applicants allows to form a general understanding of the trend in the development of additive manufacturing in the Russian Federation. Figure 1 shows the distribution of the number of patent documents included in the found patent families over time.

![Graph showing the dynamics of patent activity from 2000 to 2021.](image)

**Figure 1.** The dynamics of patent activity from 2000 to 2021. Built by the author on the basis of data from [6]

The overall dynamics of the Russian segment is characterized by a positive trend until 2018 year. There has been an annual increase in the number of documents since 2001 year in relation to the previous year. It allows to come to the conclusion about the gradual development of the field of laser additive manufacturing in the Russian Federation. The decrease in activity after 2018 can be explained by the effect of US and European Union sanctions in 2014 prohibiting the export of lasers and dual-use products to the Russian Federation. Also in 2017, sanctions were imposed personally against Valentin Gapontsev, the head of IPG Photonics, the world leader in the production of fiber lasers actively used for additive technologies [7]-[9]. This led to a decrease in the number of applications submitted primarily by foreign companies. At the same time, the USA is the leader of the world market of additive manufacturing. A new wave of patenting in the field of additive manufacturing should be stimulated due to the fact that a preliminary plan for the development of additive
technologies in the Russian Federation until 2025 has been formed. It was happened during a meeting of the specialized Interdepartmental working group on the development of additive technologies with the participation of Rosstandart, specialized research institutes, Rostec, Roscosmos and Rosatom at the international industrial exhibition INNOPROM-2018 [10]. The Association for the Development of Additive Technologies has been formed in the Russian Federation [11]. It allows to guarantee the financing of domestic projects in this area in the near future.

The results of identifying the leading copyright holders in the field of laser additive technologies on the territory of the Russian Federation are shown in Figure 2. The French company "Safran Aircraft Engines" (data on the country's affiliation are taken from the sample frame of patent families obtained from the patent holder address column [6]) ranks first in the number of patent families in the rating of copyright holders. It has registered 46 inventions in the field of laser additive technologies on the territory of the Russian Federation. This company is one of the world leaders among aerospace corporations in the development and production of aircraft engines, its Russian patent portfolio includes 124 inventions. The Russian university "Moscow State Technological University Stankin" is a machine-building university and one of the nine system-forming universities in Russia ranks second in the ranking with 24 registered patents. The Italian company DWS is next in the ranking. It specializes in the creation of stereolithographic 3D printers. It has the rights to 21 technical solutions from this field of additive manufacturing. Two American companies, Boeing and Xerox, complete the top five leaders in patenting in the field of additive manufacturing on the territory of the Russian Federation. These companies have 19 and 17 patent families, respectively. The top thirty patent holders include only four Russian representatives. This allows us to come to a conclusion about the attractiveness of the Russian market of laser additive manufacturing for foreign companies and the serious development of these technologies in our country among domestic companies is just beginning. Chinese patent holders are not represented among the top 30 patent holders, and among the Chinese copyright holders found, none of them has a large patent portfolio. This indicates their interest in developing other markets in this area, in particular the US market and their own. Global manufacturers of equipment for additive technologies such companies as EOS (Electro optical systems, Germany), specializing in the production of 3D printers for selective laser synthesis of products made of powdered metal materials and Arcam (Sweden), specializing in the creation of equipment and technologies for electron beam cultivation of metal products, are actively patented in our country. There are many companies working in the energy and aerospace industries among the rights holders on the domestic market. This suggests that the protected technical solutions from the field of laser additive manufacturing will be used mainly in these areas.
Figure 2. Rating of patent holders by the number of patent families. Built by the author on the basis of data from [6]

The results of the analysis of the frequency of occurrence of inventors in the found patent documents are shown in Figure 3. It shows that the leading positions in the rating of inventors in the field of laser additive manufacturing were taken by Russian (for example, Saprykin D. L., Saprykin L. G., Tarasova T. G., Dubovtsev V. V., Turichin G. A.), German (for example, Philippi Jochen, Kamel Ahmed, Bruck G. J.) and Japanese inventors (for example, Hamamura Hideyuki, Sakai Tatsuhiko). Also in the rating there are authors from Italy (for example, Zenere Sergio from DWS and Costabeber Ettore Maurizio, who is an independent inventor) and France (for example, Mottin Jean-Baptiste and Gaignon Richard).
Figure 3. Rating of inventors by the number of mentions in individual patent families. Constructed by the author on the basis of data from [6]

The results of the analysis of the frequency of occurrence of inventors demonstrate the predominance of Russian authors among the selected patent documents in the field of laser additive manufacturing. They took 11 of the 27 leading positions. At the same time, there is a significant number of foreign authors (German, Japanese, French). This confirms the interest of foreign companies in the Russian market of laser additive manufacturing. Figure 4 shows the results of the analysis of the activity of companies in patenting their solutions by the years of filing the first application from the patent family. These data allowed to determine when companies were most active.
Figure 4. Activity of the leading patent holders by year. Constructed by the author on the basis of data from [6]

The area of the circle in Figure 4 indicates the share of the number of patent documents from the total number of selected documents in the sample. From the presented data, it can be seen that the main activity in the submission of applications from the leading companies occurred in the period from 2011 to 2018. Some companies, such as the German Siemens Energy and the American IPG Photonics, were most active on the Russian market in this area only during this period. A significant surge in activity was observed in 2005 and 2006 at the French company Safran Aircraft Engines and the German company EOS. The analysis of the geographical scope of legal protection serves to determine the leading countries in the technological field under consideration. It also allows you to identify the most promising markets from the point of view of copyright holders. In this study, the Russian segment of patent documentation in the field of laser additive manufacturing was analyzed. Only those countries of companies that patent their technologies on the territory of the Russia were considered. Figure 5 shows the distribution of priority countries by the number of patent applications filed.
Priority countries by the number of patent applications filed. Constructed by the author on the basis of data from [6]

As a result of the research, it was found that patenting in the Russian Federation is mainly carried out within the framework of European applications through the European Patent Office EP (717), or directly through Rospatent RU (215). A significant proportion of applications relate to technical solutions originally registered in the United States US (35), sometimes patenting occurs within the framework of international applications WO (13) and only once after the registration of the solution in France FR. The USA, Germany, Japan, France, Italy, Holland, Switzerland, Sweden are the leading countries actively defending technical solutions on the Russian market in the field of laser additive manufacturing. The largest number of patent applications filed after Russia belongs to the United States, Japan and Germany. This is quite predictable, since these countries, along with China, are world leaders in the use of laser additive manufacturing. Other countries are just beginning to enter the Russian market in this area, as a result, their presence is still insignificant. Patent analytics often draws conclusions based on the study of such an indicator as the codes of the International Patent Classification (IPC). The analysis of the number of patents related to the most frequently mentioned IPC codes helps in identifying the most significant areas of application of technical solutions in the
field of laser additive manufacturing. The distribution of the studied patent documentation by IPC codes is shown in Figure 6.

Figure 6. Distribution of patent documents by IPC codes. Constructed by the author on the basis of data from [6]

Most often, applicants patent developments in the field of laser additive manufacturing in the IPC B23K26/00 subclass "Metal processing with a laser beam, for example, welding, cutting, hole formation". And also in subclasses B33Y10/00 "Processes of layer-by-layer synthesis technology", B22F3/105 "Methods and devices for manufacturing a workpiece or a product made of metal powders - using electric current, laser radiation or plasma" and B33Y30/00 "Devices for layer-by-layer synthesis; structural elements or accessories for them". Also a popular subclass is B29C67/00 "Technical methods of shaping that are not assigned to groups 39/00". For a general understanding of the main categories, which include technical solutions proposed by inventors in the field of laser additive manufacturing, an analysis of the descriptions was performed. The descriptions were studied by the presence of search keywords in them and the IPC indexes used. This made it possible to form clouds of key phrases by areas of application in the main areas of technologies that arise based on the separation of the IPC classes selected for the search (Technology domain). The results of the analysis are presented in Figure 7.
Figure 7. Distribution of the patented solutions of the leading patent holders by technology areas based on the IPC codes used and the areas of application specified in the patent description. Constructed by the author on the basis of data from [6]

In Figure 7, the darker the area, the greater the number of sample documents related to it. It is clear that the leading patent holders protect their solutions in the fields of tool equipment, materials and metallurgy and other specialized equipment. In addition, active developments are underway for such areas as coating technologies, textiles and paper machines, optics, pump and turbine engineering.

The main categories of concepts used in the descriptions of patented technical solutions in the field of laser additive technologies were laser radiation, microstructure, laser welding, laser processing, 3D printer, laser light, layered production, molten bath, powder layer. This indicates that methods for optimal material processing are being developed in laser additive manufacturing. The material is usually in the form of a powder. During the processing, the features of laser radiation and the properties of the melting pool are taken into account. 3D printers or equipment for layer-by-layer production or processing of metal products are also being created, allowing to obtain a unique microstructure.

4. Conclusions
- Companies from the USA, Germany, Japan, France, Italy, Holland, Switzerland, Sweden and Russia are bringing their technical solutions to the Russian market in the field of laser additive manufacturing.
- DWS (Italy), EOS (Germany), Arcam (Sweden), energy and aerospace companies, technical universities compete with each other in the Russian market for equipment for additive manufacturing.
• Russian and Japanese authors are the leaders among inventors in the field of additive manufacturing in our country.
• 3D printing of products made of metal materials is the most promising field of laser additive manufacturing in the Russian Federation. It is advantageous to patent new technical developments in the field of materials and metallurgy of processes, as well as those related to tool equipment or other additional equipment.
• The aerospace industry is the most promising area of application of additive manufacturing. The French company Safran Aircraft Engines is the leader in the number of patents.

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