State and prospects of industrial robotics in shipbuilding

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Abstract. The production process of any type of product today is difficult to imagine without the use of industrial robots. Their versatility, production flexibility and wide technological capabilities make them an indispensable tool in modern manufacturing, including in such economically and strategically important industry as shipbuilding. In this regard, according to the authors, it is advisable to analyze the current situation and prospects for the use of robotization in industry, in particular, shipbuilding in Russia and abroad. The article presents statistical data on indicators of the level of robotization of domestic and foreign industry; describes the trends in the development of industry during its robotization, indicates the scope of application of industrial robots, etc. The factors of expediency of using robots in industry are analyzed. The inevitability of the general growth of industrial robotization and, as a result, a change in the economic structure in developed countries and, possibly with a certain lag in Russia has been substantiated. Identified problematic issues associated with the introduction and use of industrial robots in the domestic industry, in particular, shipbuilding.

1. Introduction
The modern economy demonstrates a constant increase in labor productivity, which is explained not only by the process of globalization and the integration of local markets in the world, but also by the new stage of the scientific and technological revolution, which has found a second wind compared to the second half of the 20th century. More and more countries in the world are faced with a problem in which production facilities become obsolete, and the technologies used on them become ineffective. Such problem, first of all, arises in the countries of the post-Soviet space, including Russia, Belarus and Kazakhstan. Many enterprises are trying to solve this problem and make the right choice: to modernize the industry, radical changes, where there will be not only new technologies, but also revolutionary inventions, including in the field of industrial automation. As a rule, managers of companies make a choice in favor of simple modernization, and complex robotization of production is only an isolated case, which is used by a few enterprises. Analyzing global experience, including such countries as the USA, Germany, Japan, China, South Korea and the United Kingdom, it is noticeable that among the key trends in the development of their industry, mass robotization and the replacement of manual and mechanized labor with flexible integrated systems play the leading role [1].

At present, the Russian shipbuilding industry, like other types of domestic industry, is at the stage of radical restructuring. Leaders of shipbuilding enterprises have to deal with the implementation of the tasks of introduction of innovative organizational and technical solutions based on the reconstruction of its production facilities both in relation to current conditions, and in the calculation of the future.
When carrying out a large-scale modernization of their enterprises, plant managers are forced to solve the issue of technological development based on foreign and partly their own developments [2].

Automation technologies and robotic systems are one of the components of automated production systems used in flexible automated production, any goal of which is to increase labor productivity and reduce costs at a constant level of quality. Automated industrial robots are used for welding, laying, painting and other operations that require repetition and high precision. It is economically advantageous to use industrial robots in conjunction with other means of automation of production (automated lines, sections and complexes) and high-precision measuring instruments.

Due to the lack of comprehensive research regarding the current state and prospects for the use of industrial robots in Russian industry, in particular, shipbuilding, according to the authors, it is advisable to analyze the current situation and prospects for robotization in industry, in particular, shipbuilding in Russia and abroad. It is also advisable to assess the current state and prospects for the introduction of industrial robots in the shipbuilding industry in Russia.

The purpose of this study is to study the current stage (state) and the development prospects of the robotization of the domestic shipbuilding industry. To achieve this goal requires:

- to review the reports of the Russian and foreign news and review press in the field of industrial robotization; provide statistical data on the indicators of the level of domestic and foreign industry robotization describe trends in the development of industry in its robotization, indicate the scope of application of industrial robots, etc.);
- to analyze the reasons for the use of robots in industry;
- to identify the problematic issues associated with the introduction and use of industrial robots in the domestic industry, in particular, shipbuilding;
- to list the directions of development of domestic shipbuilding in modern conditions

2. Statistical data
2.1 Amount of sales of industrial robots
According to the International Federation of Robotics (IFR), in 2017, sales of industrial robots increased by 30% - to 381,300 units, reaching a new maximum. This means that over five years (2013-2017) the annual sales of industrial robots increased by 114%. In monetary terms, this is $ 16.2 billion, but this amount does not include software, peripherals and integration services (with them the market is estimated at $ 48 billion). The IFR forecast shows that in 2021 the annual number of robots shipped to factories around the world will reach about 630,000 units. The average annual sales growth rate for robots is 14%.

The total global fleet of industrial robots in operation at the end of 2017 increased by 15% to 2,098 thousand units. In subsequent years, growth will accelerate slightly and is expected to be about 16% on average per year. By 2021 the average annual growth forecast for Europe is 9%, and for America - 10%.

73% of global sales of industrial robots are in five countries: China, the Republic of Korea, Japan, the United States and Germany. Japanese manufacturers supplied 56% of global supply in 2017. This makes Japan the world's largest manufacturer of industrial robots.
2.2 Robotic automation of production in Russia and abroad

From year to year Russia takes one of the last places in the annual global ranking of production robotization, which is held by the IFR for the Information Technology and Innovation Fund (ITIF). The ranking includes the number of industrial robots per 10,000 production workers in the country. According to information published by the IFR in the Information Technology and Innovation Fund (ITIF), the global average in 2017 was 85 robots per 10,000 employees. This is 15% more than in 2016.

South Korea is still the world leader, increasing to 710 robots by 10,000 workers, followed by Singapore with 658 robots and Germany with 322 robots. Russia and India close the rankings from 27 countries with rates of 4 and 3 robots per 10,000 production workers, respectively.

However, a simple calculation of the number of industrial robots is not the only way to measure the effectiveness of automation of labor. A new report from the ITIF is another metric, where the number of robots per 10,000 production workers is normalized by the level of the labor of these workers pay.
This is a rather interesting result, because economics assumes that the main incentive for the introduction of robots is a high level of remuneration of human workers. The higher the level of remuneration, the greater the incentive for the introduction of robots, who are ready to work almost free of charge around the clock, do not arrange strikes and do not commit suicide.

Figure 3. The number of robots per 10,000 workers in 2017 with the normalization of the size of the population’s wages. After this normalization, the countries of South-East Asia lead in the ranking. Source: ITIF

Figure 4. The number of robots per 10,000 workers in 2017 with the normalization of the size of the population’s wages. Source: ITIF
Introducing robots to production is a costly investment, so if there is cheap work force, there is not much point in installing high-tech equipment — one of the reasons why the number of industrial robots in Russia and India is so insignificant.

After the normalization of wages, the countries of Southeast Asia are now even more dominant than before. On the top lines there is South Korea and Singapore with coefficients of adoption of about 2.4 and 1.7 times. The adoption rate is calculated relative to the average of what one would expect based on the current average wage. Even countries like Thailand, which has only 48 industrial robots per 10,000 production workers, have an adoption rate of 159% higher than the wage levels that could be predicted.

On the other hand, it is found that most countries in America and Europe are introducing robots much slower than expected. The US and UK showed an adoption rate of 49% and 68% less than expected.

The reasons for this "love" for robots in Asia and "dislike" in Europe and the United States are not well understood. It may be a matter of the attitude of the nation to work, respect for human rights and the power of trade unions.

It should be noted that even after normalization of wages Russia occupies the last place in the ranking. The last lines at a rate of "rejection" of robots with normalization of wages of workers, together with Russia, are shared the United Kingdom, Australia, Brazil and Switzerland.

According to ITIF experts, "robots are key tools for improving productivity and living standards." Initially, they were used in production, but as scientific and technical advance progressed, robots found application in many other sectors: from agriculture to logistics and hotel business [3].

2.3 Some reasons for the lag in the introduction of robots in Russia
Taking into account the statistical data, it is obvious that in Russia the mass robotization of the industry is late, as is the development of robot building as a whole. The last significant successes in the development and production of industrial robots belong to the Soviet Union. In the USSR, robots became an obsessive dream of several generations: they were designed to save people from hard manual labor. The rest of the world had another incentive to create and implement industrial robots: cost savings and increased productivity were valued far more than the social component.

After the collapse of the USSR, the industry of industrial robotics was practically lost, and even now, by many estimates, the volume of the robotics market in the country is scanty. The Center for Innovation Consulting "Larza" estimates it at 0.17% of the world.

According to Konstantin Zherebyatiev, the chief designer of Robokon, in 2013, no more than 350 industrial robots were sold in the country, and even fewer in 2014: some system integrators claimed that the transactions were single. The most developed industry - robots for the automotive industry - has lost consumers due to the economic downturn. In addition, the main supplier of Russian robots for AvtoVAZ, the Volzhsky Machine-Building Plant, was "on the verge of life and death" last year: it was declared bankrupt, they sold Rosnano for debt, and they bought it back. Perhaps, only Russian system integrators achieved some success. Dozens of domestic companies today offer their services for the development and implementation of integration projects based on imported robots, supply, installation, commissioning and commissioning of equipment and subsequent technical support.

There is no demand for robotics in Russia, because there is no need for efficient production", says Albert Efimov, head of the Skolkovo Foundation Robotic Center. Robotics arise where all existing production problems have already been solved. Industrial automation is resorted to when it is necessary to improve the accuracy of production or to reduce losses, and all other methods have already been used for this. But in Russia there are so many problems associated with production losses that automating the work of people is far from the most important task.”

This also implies the second reason for the slow introduction of robots in Russia. The foundation of the industrial machine park in Russia is equipment manufactured in the 1970s and 1980s. Such machines are not subjected to automation, because the necessary control interfaces are physically deprived. In domestic factories, it is easier to remove all the “stuffing” and install new robotized lines than to try to upgrade the existing equipment. This requires too much investment.

Thus, low-paid (in comparison with developed countries) human labor in Russia is still cheaper than robots.

Attempts of applied developments of competitive products for the mass market in Russia are only emerging. Russian robotics in its development rests on high production costs and interest rates. The lack of
high-quality domestic components and the associated expensive delivery and customs clearance of imported components also hinder the development of robot-building industries [4].

3. The current state of the shipbuilding industry in Russia and abroad

Shipbuilding is one of the most important industries in Russia with great potential. Being one of the most high-tech industries, it requires large investments, but it also gives large profits, which makes it possible to improve the economic situation in the country and increase GDP. The geographical position of Russia - the country has 44,000 km of sea borders, as well as hundreds of thousands of river routes - is one of the most favorable for the successful functioning of the industry.

In the current tense political situation, the development of the defense complex, including the navy, is very important. All these factors make the development of the shipbuilding industry one of the most pressing problems for the country's economic well-being.

In the 90s of the 20th century, the shipbuilding industry, like many other industries, was in crisis. Reduced funding or the lack of it made it impossible to operate shipyards and factories at full capacity, which led to the decline of the shipbuilding industry. The number of defense orders of the Navy, as well as research works has decreased. Their volume decreased about 5 times.

Economic growth in the early 2000s brought new orders and investments to the shipbuilding industry, but this was not enough to return the work of factories and shipyards to the volume of products manufactured before the restructuring.

Currently, military shipbuilding occupies about 75% of the total production of shipyards. It is financed by the state and is expressed in the form of defense orders carried out by factories and shipyards throughout the country. A large share of military shipbuilding, as well as the high quality of the ships launched, allows Russian shipyards to enter the international market and compete with foreign shipyards. About 12% of world military shipbuilding is provided by the production of Russian shipyards. If we consider the share of exported vessels in the total number of vessels launched in Russia, it will be about 21%. The share of exports of military courts is quite impressive, especially against the background of exports of civil shipbuilding, which accounts for only about 2% of the world market. The share of exports of civil shipbuilding is very small. It is very difficult for ships launched in Russia to compete with ships launched in Korea. This is due to the low cost and low price on the world market, respectively. Russian ships are not inferior in quality, but in the current situation, price remains one of the main indicators. The high cost of domestic ships is influenced by many factors originating in the last century.

Historically, the Russian shipyards and shipyards were focused on military shipbuilding. Reorientation to civil shipbuilding requires costs, which negatively affects pricing. The period of restructuring was marked for the shipbuilding industry by the almost complete lack of funding for research and development. Since shipbuilding is a high-tech field, it is developing rapidly and requiring constant new developments, the reduction of which in the 90s of the last century has led to huge costs now for the possibility of launching modern ships. This also negatively affects the pricing of final products. Imperfect Russian legislation leads to additional costs for paying all taxes, and the unsustainable exchange rate of the Russian ruble, foreign sanctions and a tense global political environment lead to a negative situation for attracting foreign investment [5].

As for the global shipbuilding market, currently three countries account for 90% of the global production and export of cargo ships - South Korea, Japan and China. At the same time, Korea is consistently the main exporter specializing in the production of high-tech large-tonnage vessels, including LNG tankers, unlike Chinese and Japanese shipbuilders, more focused on meeting domestic demand. According to Russian industry players and major customers, depending on the ship’s specification, the period of its construction in Russia is 2-3 years longer, the cost is 30-40% higher than the Korean equivalent, and the lack of experience and necessary competencies does not guarantee quality operation. The complexity of the construction of tankers in Russia is much higher than abroad, due to the lower level of production automation and quality control, as well as due to the high labor costs for the design of the vessel [6].

In order to compete with Asian leaders and meet domestic demand in large-capacity ice-class vessels, Russian shipbuilders will have to work ahead of the curve. If in South Korea, the construction of commercial ships has been developing since the 70s of the last century, in China since the 2000s, domestic shipyards will have to master the unique competencies in the next decade.

The basis of the reconstruction of the world's leading shipyards in the 21st century is the principle of
transition from automation of individual technological operations (pre-processing, thermal cutting of sheets on CNC machines and profiles on robotized complexes, robotic welding of components, etc.) to full automation and robotization of shipboard production with the introduction of new technologies that ensure the transition to a qualitatively new level of production in terms of economy, productivity of ship hulls [7].

It is important to note that shipbuilding is an industry that has a large production and scientific and technical potential that influences the development of technology in related industrial sectors: metallurgy, chemical industry, instrument engineering, robotics, electronics, and therefore it is necessary to predict economic growth in the whole country. In addition, the factor of robotization of production will lead to the elimination of low-skilled labor with a simultaneous increase in high-skilled jobs.

4. Industrial robots in shipbuilding

Let us consider in more detail the use of industrial robots in shipbuilding on the example of foreign industries.

Two of the leading companies in the field of robotics, Daewoo and Hyundai, are at the same time one of the largest shipbuilders in the world. The companies plan to use a welding robot in the near future, which, according to experts, will shorten the welding time by two thirds and save about 10 billion won ($9.4 million) per year. To further automate its shipyards, Hyundai Heavy is developing other robots for welding and paintwork.

Daewoo Shipbuilding uses the Caddy 16kg robotic arm to weld steel parts during the construction of gas carriers. This robot is able to work with the body, welding steel structures in a confined space. Caddy has helped Daewoo Shipbuilding save about 4.5 billion won in the cost of building each gas carrier since 2016. Daewoo also plans to use innovative robotic exoskeletons to make the workflow more efficient [8, 9].

At Samsung Heavy Industries Geoje shipyard, a spider-robot was designed to clean the surface of the vessel before painting. The same company has created a robot that examines the places of the vessel where welding is necessary [10].

Several years ago, General Electric (GE) provided the Dalian Chinese shipyard with smart loaders with a length of more than 100 meters and a weight of 600 tons, controlled by a computer system. Currently, two such loaders are working synchronously at this shipyard.

At the GE Oil & Gas plant in Talamone in 2016, two high-tech production lines were opened. They use two anthropomorphic robots capable of using 10 different technologies, including EDM, measurement and laser welding [11].

For the US Navy, robotics at the Polytechnic Institute and the State University of Virginia are developing an anthropomorphic shipboard autonomous fire-fighting robot Saffir (SAFFiR). The choice in favor of a humanoid robot was made because of the difficult conditions in which it would have to move on the deck and inside the ship. In the future, “hybrid units based on the interaction of robots and humans” will be created [12].

Structurization of technical and technological problems in the construction of ships has shown that robotic tools can be effectively applied in the following industries: assembly-welding and building stocks, foundry, turning (rebar), painting.

In the assembly-welding and stapling production, industrial robots can be used, fixed at the workplace, made in the form of a manipulator with welding equipment applied on it. They will be able to solve the problems of welding the kit, section parts and their welding, as well as welding in hard-to-reach places. In addition, with the help of robotic tools, it is possible to facilitate the assembly of the section for welding, since the robot can solve the problem of fixing individual hull elements at the installation site according to the working design and technological documentation to ensure welding. This must be equipped with specialized grippers (mechanical, magnetic, etc.) and be able to withstand the multi-ton loads on the design of the manipulator itself. In addition to welding and fixing, robotic tools can be assigned the function of pressing equipment for local reshaping the shape of the body parts of a section or their element. Therefore, its creation is the most time-consuming.

In the foundry industry, robotic tools can be applied in the form of industrial robots fixed in the workplace, made in the form of a manipulator, with cutting equipment (milling or turning) applied on it. This equipment can be used to produce a model with a method of investment casting, turned out by a robot,
according to an electronic three-dimensional model.

In the turning (reinforcing) production, robots fixed in the workplace, made in the form of a manipulator, with metal-cutting equipment (milling, turning) applied on it, as well as tools for grinding can be used. A scope - turning processing of the preparation, difficult in a form, and details made with high precision. An example would be the turning of a propeller billet.

When painting, a robot can be used, made in the form of a manipulator fixed at the workplace or mobile anthropomorphic, depending on the specific task. Such a manipulator should be equipped with paint or polymer coatings. A scope - coloring of hard-to-reach spots (tanks, the second bottom, double bottom and inter-breasted space, and also volumes inside a forepeak and afterpeak). In addition to the above, the coloring and application of toxic and explosive materials inside the closed volumes.

At the shipbuilding enterprise, in addition to the listed production, you can use various manipulators when working with hazardous materials, goods, for example, in electroplating or in the organization of a warehouse. But such tools can hardly be called robotic, since they will be under the direct control of the operator.

It should be noted that in most of the production described, robotics will be in close proximity with a person, and strict safety requirements will be applied to it, including the possibility of discontinuing autonomous operation.

5. Conclusion
Experience of developed countries does not cause optimism in the introduction of industrial robots in the Russian Federation. The density of robotization in Russia is 21 times lower than the world average, and 30 times lower than the average in Europe. The average annual sales of industrial robots in Russia are 500–600 units (in 2015, they were sold to 550), and this is about 0.25% of the world market. If in South Korea there are 531 robots per 10 thousand people, in Russia there are only 3.

The lack of effective robotic industries in domestic shipbuilding, the rapid pace of industrial development, the complexity of ships under construction and the intense competition in the global shipbuilding market require radically new solutions to improve the quality of construction of new ships and ships:
- the most important direction of development of domestic shipbuilding in modern conditions should be the introduction of end-to-end group robotized and automated technology based on highly concentrated energy sources;
- the latest technological processes capable of causing revolutionary changes in the shipbuilding industry are laser, plasma technologies (laser cutting, marking, marking, bending and welding), high frequency current welding technology;
- the most important direction in improving shipbuilding efficiency should be the widespread use of cellular steel panels manufactured using laser welding and precision welded aluminum panels obtained using preliminary elastic stretching and transverse bending;
- comprehensive introduction of the latest robotized and automated group technologies at shipyards of various classes will ensure a reduction in the specific labor intensity of building hulls of ships several times as compared to the currently existing ones in domestic shipyards, as well as an increase in production [7].

Thus, the basis of the strategy for reforming domestic shipbuilding should be the concept of technological reform, in particular, the robotization of production. Based on this concept, it would be advisable to build new and modernize existing shipyards.

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