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THE MAIN TENDENCIES OF DEVELOPMENT OF AUTOMATION AND ROBOTIZATION IN WELDING ENGINEERING (Review)

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The paper represents arranged economical-statistical information on development of automation and robotization in welding engineering. Currently, the main peculiarity of the world economy is application of advanced automated (robotic) systems. Decrease of expenses for re-equipment of enterprises due to cost reduction of robots, computer numerical controllers, automation hardware and software promotes investment in automation of commercial production. 14 Ref., 4 Tables, 8 Figures.

Keywords: *welding, automation, robotization, welding robots*

Currently, the main peculiarity of the world economy is transfer from era of industrial automation to ever kind application of advanced automated/robotic systems in manufacture. Wide implementation of information and computer technologies have changed a concept of automation of modern production and formed a potential for its global growth. The market of automation means and technologies has become attractive in terms of direct investments all over the world. An average annual sales growth at the world market of production automation in course of last 10 years made around 6.6 %; in 2015 volume of sales exceeded 185 bln USD and following the forecast [1] will reach 352 bln USD till 2024.

The main reason of investment attractiveness for commercial production automation became significant decrease of expenses on enterprise re-equipment. Cost reduction of robots, computer numerical controllers, automation hardware (probes, processors) and software resulted in cut down of payoff period of technological equipment and investments. An average price of a robot in 2015 has dropped by 30 % in comparison with 2000. Data on spot welding robot price can be presented as an example. Based on data of Boston Research Company (BSG) its price has reduced by 27 %, on average from 182 thou USD to 133 thou USD (in comparison with 2005), and till 2025 its decrease will make 22 % more. Drop of hardware and software price is expected in the near decade and can make more than 20 %.

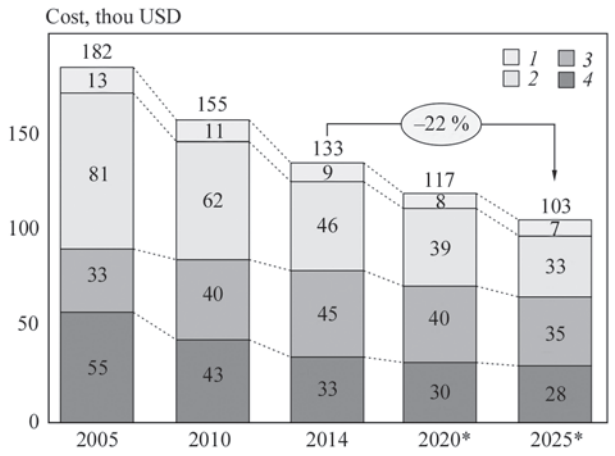

Figure 1. Dynamics of change of cost structure of a system for typical spot welding robot in motor car construction industry of the USA (* — prediction): *1* — project management; *2* — system engineering; *3* — peripheral devices; *4* — robot

Dynamics of change of a cost structure of standard robot for resistance spot welding in motor car construction, according to data [2, 3], is given in Figure 1 [3]. Decrease of expenses on management of projects on robot implementation in production and reduction of system engineering cost due to advantages of offline programming are expected in a period till 2025. Removal of the safety barriers and probes results in cut down of expenses on peripheral devices. Insignificant fall of robot price (including software) can take place since it approaches to material expenses and production volume in the motor car industry is already high.

At the same time, according to the prediction, productivity of the robotic systems will annually rise approximately by 5 %. Currently, robots perform more than 10 % of all manufacturing operations and in 2025 more than 40 % of all manufacturing operations in industry will be performed by robots.

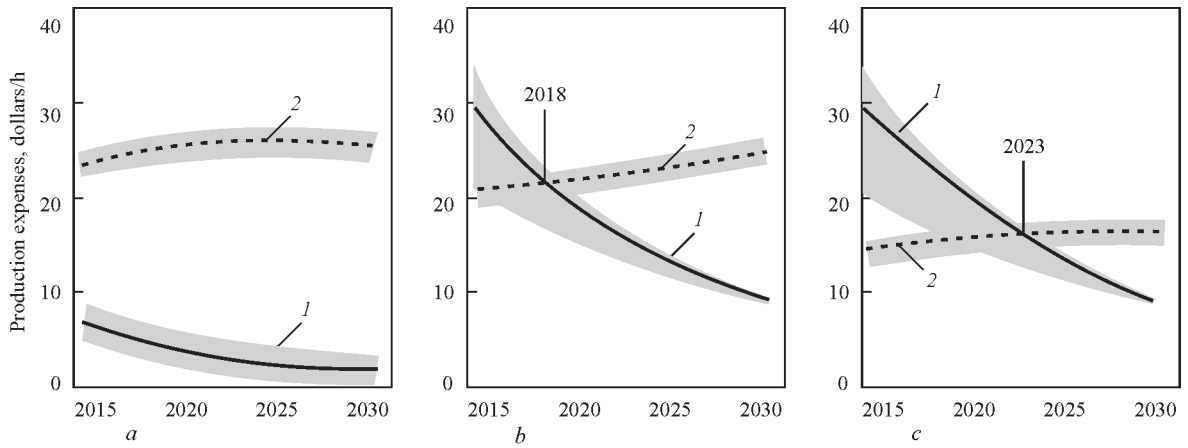

Figure 2. Comparison of production expenses in application of robots (*1*) and worker labor (*2*) in series of branches of USA industry: *a* — motor car construction; *b* — electric equipment; *c* — furniture production

Steady reduction of robotics price makes it more attractive for small and medium-sized enterprises and opens new possibilities of their wide application, thus in turn allows increasing labor productivity in many activity spheres.

Labor shortage on the world labor market is also a strong reason for implementation of robotics in industry. Based on data of the American Welding Society shortage of welders in the USA in 2020 will make around 290 thou workers and these working places will be replaced by robots. In accordance with the report «Future of automation» from ARK Invest approximately half of the working places in the USA will be automated and robotized till 2035. The report notes that automation promotes 103 % increase of additional labor cost per one dollar release and add 12 trn USD to real total GDP. Increased productivity being provided by automation will have large effect on economic growth, moreover real GDP per one worker in the USA will double from 113 thou USD in 2013 to 236 thou USD in 2035 or at an annual rate by 3.4 % [3, 4].

The data, presented in Figure 2 [3], show that robotics is already economically viable alternative to human labor in many branches of USA industry.

Modern market becomes more and more dynamic. Decrease of product life cycle, necessity in quick change of output product line, consideration of individual needs and wishes of customer during product manufacture is the key to success in a global scale competition. All this requires rapid adjustment, high accuracy and coordination in the production line and it is difficult to fulfill using workers labor. Production automation makes it possible as well as determines growth of a demand in versatile and programmable automated equipment. One of the solutions for these problems was development of new generation robotics being collaborative and directed on joint work of robot and human. They have already started replacing the generation of «isolated» robots.

Present investigations show that joint work of robot and man is 80 % more productive than their individual work. Cobots (co-robots) are the new robots designed by pioneers of the market (Baxter from Rethink Robotics, Universal Robot) and world leaders such as ABB and KUKA. Cobots' developers have proved that virtually any modern robot can be transformed in a certified cobot, completely safe for human. It is only necessary to reset its control system and teach it to «listen to» new sensors.

The Universal Robots sold the first in the world cobot, as they were nicknamed, in 2008. It happened long before a term for this new class of robots started being widely used. Today this is the most rapidly growing segment of the world robotics market, which based of analytics' forecast will annually rise by 50 % and it is expected that in 2020 its volume will reach 3 bln USD [5].

An industrial robots (IR) demand shows the most dynamic growth in a segment of automation means, which in a structure of world automation market makes around 4 % and 17 % account for them in a structure of world market of automation means. Industrial robots perform technological operations quicker and more accurate than human, provide increase of productivity and decrease of total production expenses in the countries with developing as well as advanced economies countries.

Table 1 [6] shows a dynamics of development of world automation market in 2011–2015.

Growth of sales income in the robotics segment for more than 40 % exceeds the average growth of sales income in the segment of automaton means and by 15 % the average growth of income at whole automation market.

Based on data of the International Federation of Robotics (IFR) the average annual increase of IR

Table 1. Dynamics of growth of income from sales of main product segments at the world market of automation means 2011–2015, %

Sales income	2011	2012	2013	2014	2015
Automation means, total including:	5.9	4.3	5.3	5.3	5.5
robots	6.6	8.3	8.6	7.5	7.5
«machine vision» devices	6.6	3.7	7.1	6.2	6.7
sensors	5.6	3.6	3.6	4.2	4.2
relay and switches	5.5	3.5	3.6	4.2	4.3
movement devices	4.9	1.5	3.7	4.3	4.4
others	6.5	6.0	6.0	6.0	6.0

sales at the world market in 2010–2015 made 16 % and average annual IR sales rose up to 183 thou units. Increase of sales by almost 60 % indicates significant growth of IR demand and investments all over the world. Total worth of IR market in 2015 in relation to previous year increased by 9 % and reached the new maximum, namely 11.1 bln USD, and taking into account software and hardware it made 35 bln USD (+15.5 %).

The world park of IR in 2015 exceeded 1664 thou units, but virtual number of acting IR park is probably significantly higher, since practice shows that the most of IR can be successfully operated after expiration of their standard service life (12–15 years). IFR forecasts that the world park of IR in 2019 will make 2.6 mln units, which is 1 mln more than in 2015.

Table 2 gives data on quantitative volume of annual sales and IR park in the world and main regions in 2010, 2014 and 2015 as well as evaluation for 2016 [7].

In the last six years application of IR trebled mainly due to Asia countries. Asian region market is the largest, fast developing market, which makes more than a half of world market. The world leaders are China, Republic of Korea, Japan as well as the USA and Germany, their total portion makes more than 75 % of the world market.

In 2015 IR sales in the Asian region grew by 20 % and made 156 thou units. China is the leader in sales growth at regional as well as world market. In 2015 the volume of IR realization in China reached 68.6 thou units that made 44 % of all sales volume in the Asian region. In accordance with data from China Robot Industry Alliance (CRIA) China has essentially increased own IR production. Volume of sales of Chinese production IR rose by 29 % at internal market in 2015 and made around 20.4 thou units, and in comparison with 2013 production increased for more than 2 times. Figure 3 shows dynamics of sales of national and foreign production IR in China [8].

In 2015 growth of IR sales continued in other countries of Asian region, i.e. Republic of Korea (+55 %; 38.3 thou units), Japan (+20 %; 35.0 thou units), Taiwan (+4 %; 7.2 thou units) and others.

Volumes of IR sales in European market in 2015 rose by 10 %, at that its main segments are Germany (20.1 thou units), Italy (6.7 thou units) and Spain (3.8 thou units). North America is also important regional IR market. Sales volumes in the USA grew by

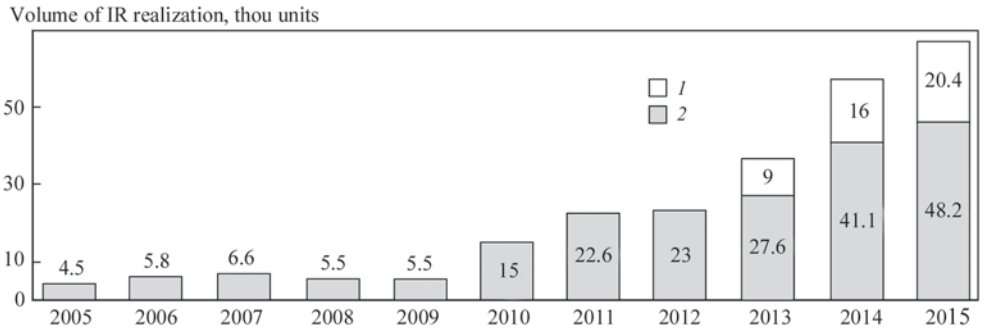

Figure 3. Dynamics of realization of IR of national (*1*) and foreign (*2*) production in China

Table 2. Number of annual sales of IR and general park of IR of all types and designations in world regions in 2010–2016, units

Region	Annual sales of IR				IR park			
	2010	2014	2015	2016 (estimation)	2010	2014	2015	2016 (estimation)
Total in the world, including:	120585	220571	253748	290000	1059162	1467900	1664000	1824000
America	17114	32616	38134	40200	179785	249500	272000	281000
Asia (including Australia)	69833	134444	160558	190200	520831	777100	1417000	908500
Europe	30741	45559	50073	54200	352142	411500	519000	431700
Africa	259	428	348	400	2232	4200	4500	4900

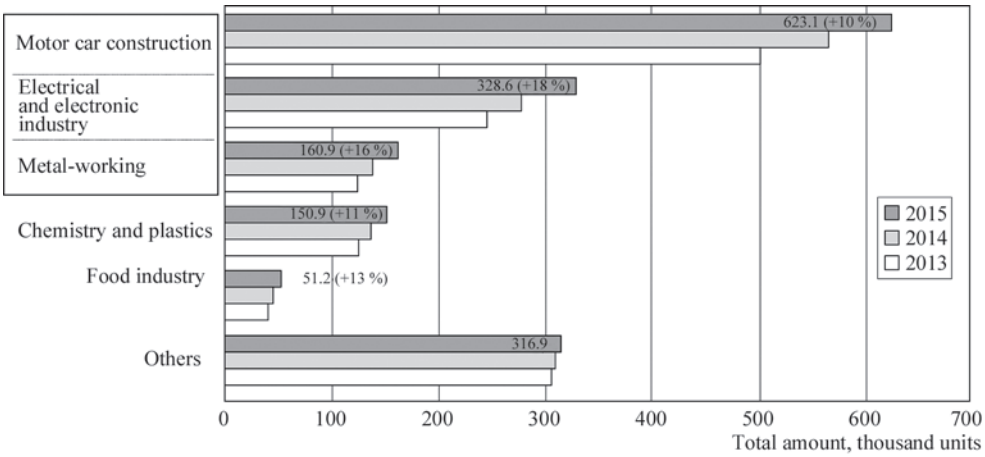

Figure 4. Number of annually installed IR in branches having the highest IR application, units

3 % and made 27.5 thou units, whereas that in Mexico increased two times and made 5.5 thou units.

In total more than 70 % of all IR sales accounts for motor car construction, electric and metal-working industry. The main consumer of IR and the main driving force for development of modern robotics is the motor car industry, portion of which makes more than 40 % of all IR sales in the world. 97.5 thou robots were installed in this branch in 2015 that is a new record for the last five years.

Significant increase of IR consumption can also be observed in electric/electron industry in manufacture of computers, medical, precision and optical instruments, telecommunications equipment and other products. In 2015 IR sales volumes in this branch increased by 41 % and reached a new peak of 64.6 thou units. Substantial growth of IR sales (+39 %) in 2015 is also noted in metal-working industry.

Number of professions successfully mastered by robots continuously grows every year. According to IFR data in the beginning of 2013 robots were already used motor car construction in a process cycle for more than 80 % of all operations, whereas in the beginning of XXI century this index made 45 % [7].

Figure 4 [9] shows data on annual installation of IR in the world in the main branches using them during 2013–2015. Figure 5 [10] presents dynamics of change of IR sales portion in motor car construction in 2005–2015.

Despite significant growth of IR market, the average level of commercial production automation in the world remains sufficiently low. In 2015 the average world index of robots density (number of IR per 10 thou employed in commercial production) made 55 units. An IR density index shows that Republic of Korea, Japan and Germany refer to the countries, commercial production of which has the highest level of automation. This index in 2015 made 478 units in Republic of Korea, 314 units in Japan and 292 units in Germany for 10 thou employed in industry.

Substantial lag in the level of robotization of branches of general machine building in comparison with motor car construction is observed. In industrially advanced countries the level of robotization of general machine building is 7–8 times lower than in motor car construction, and 19 times in BRIC countries. This is an impetus and potential for development of robotics market in industrially advanced countries as well as developing economy countries. Figure 6 [9]

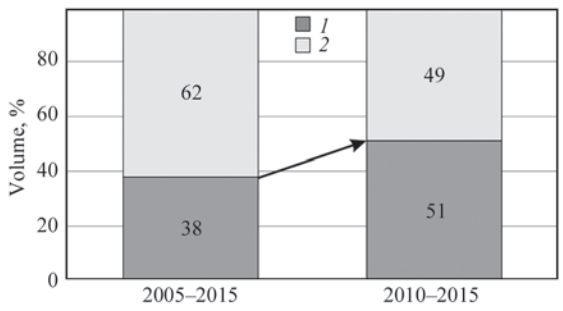

Figure 5. Dynamics of change of IR structure in motor car construction (*1*) and other branches of machine building (*2*), %

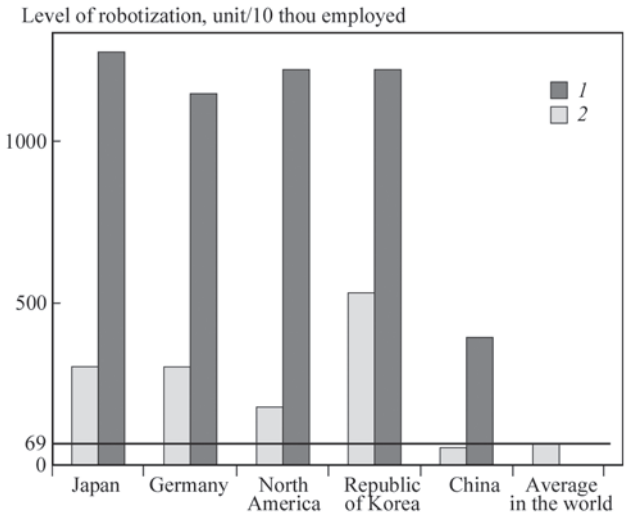

Figure 6. Density of IR in motor car construction (*1*) and branches of general machine building (*2*) in 2015

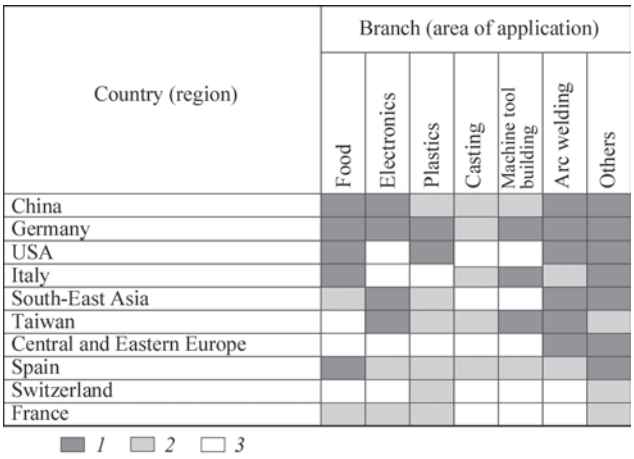

Figure 7. Evaluation of level of robotization in branches of general machine building in regional section on quantitative volume of IR annual sales: *1* —high (more than 300 units); *2* — medium (150–300 units); *3* — low (less than 150 units)

presents data of the level of robotization in motor car construction of Japan, Germany, USA and series of other world countries [7, 9].

Motor car construction in comparison with other branches of industry is the most automated branch. Motor car construction enterprises with the highest level of robotization are located in Japan, Republic of Korea, Germany and USA. High level of robotics is in electron industry of Japan and Republic of Korea.

Experts of KUKA Company based on IFR data and IR sales volume in 2013, has evaluated the level of robotization of general machine building branches in ten countries/regions of the world, where 80 % of the world market of general machine building are concentrated. Figure 7 shows the results of carried analysis [11, 12].

Data show (see Figure 7) that there is a significant potential for IR market growth in the most branches of general machine building of industrially advanced countries as well as developing economy countries.

The highest demand at the world IR market has robots for material treatment, their park makes 38 % of all world IR park and includes robots for casting, heat treatment, stamping/forging.

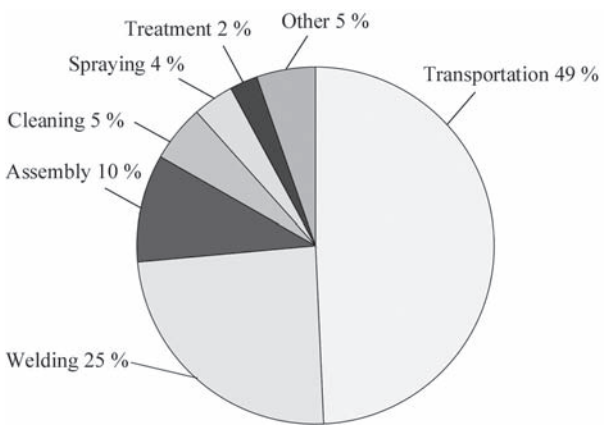

Figure 8. Structure of IR sales on types of technological operations for 2015

Robots for assembly make around 10 % , that for coating deposition is 4 % and special processes (laser and plasma cutting, water jet cutting etc.) 2 % of the world IR park (Figure 8 [7]).

In scope of global research of robotics market BSG Company predicts 10.4 % growth of annual average rate till 2025. Among them 10.1 % of annual growth of robot sales in production comes for welding, assembly, painting, loading-unloading operations and other types of work. Volume of sales will increase from 5.8 bln USD (in 2010) to 24.4 bln USD (in 2025). Thus, this robotics segment, regardless lower growth rate, will keep larger portion of robotics market. Around 8.1 % of annual sales growth accounts for the robots used in military purposes, first of all UAV, military exoskeletons, underwater vehicles and ground transport vehicles. Their sales volume will rise to 16.5 bln USD till 2025. For example, in Russia portion of military robots makes about 50 % of all IR park [3].

Estimation of IFR and series of analytical companies shows that welding robots makes 25–30 % of the world IR park or about 500 thou units. They mainly include robots for arc and spot welding. Portion of robots for arc and spot welding makes around 50 % in quantitative and monetary terms in the structure of world market of welding robots.

A structure of welding robots market in the regions significantly differs. The robots for spot welding dominate at the European and American markets (about 70 %) and arc welding robots (60–70 %) prevail at the Asian countries markets.

Volume of sales of the welding robots at the world market rises almost by 50 % from 33 to more than 59 thou units during 2008–2015. Countries of North America (23 %), China (21 %), Europe (18 %) and Japan occupy the main portion of the market (more than 70 %).

World market of welding engineering in 2016 reached 24.2 bln USD. It is expected that the market will rise by 5.6 % every year within the next five years. A segment of robotized welding equipment in the structure of this market makes about 12 % (2.8 bln USD), at that it is supposed that its average annual growth will make about 7 %.

Countries of Asian region cover almost 60 % (China — 21 %), that of Europe is 18 % and North America makes 23 % in the regional structure of sales of world market of welding robots. Portion of welding robots in the sales structure at national IR markets varies from 20 % in Malaysia to 62 % in India. In China this index in 2015 made 36 %, in Brazil 38 % and 24 % in Russia.

Table 3. World market of welding robots in 2015

Country	Robots for arc welding		Robots for spot welding		Total	
	pcs	%	pcs	%	pcs	%
Europe	3400	32.1	7200	67.9	10600	17.9
Russia and CIS	330	60.0	220	40.0	550	0.9
China	7600	61.8	4700	38.2	12300	20.7
Korea	3000	61.9	1850	38.1	4850	8.2
Japan	3520	56.6	2700	43.4	6220	10.5
Taiwan	780	75.7	250	24.3	1030	1.7
India	810	40.3	1200	59.7	2010	3.4
ASEAN	2550	54.3	2150	45.7	4700	7.9
the Near East	260	47.3	290	52.7	550	0.9
Africa	270	54.0	230	46.0	500	0.8
Oceania	320	49.2	330	50.8	650	1.1
South America	4800	34.8	9000	65.2	13800	23.3
Central and South America						
America	770	50.7	750	49.3	1520	2.6
Total	28410	47.9	30870	52.1	59280	100.0

Source: The Japan Welding News for the World.

According to data of the Japan Welding News publication more than 59 thou welding robots were installed in the world in 2015, among them 52 % are the robots for resistance welding and 48 % for arc welding. Table 3 shows data of the welding robots market in 2015 [13].

The world market of welding robots is flourishing and demonstrates continuous growth in the recent years. This process is significantly promoted by high rate of growth of motor car construction in China and India. An exceptional demand for welding robots is observed in general machine building.

A bias of world commercial production in the Asian region promoted decrease of prices for welding robots in short-term and long-term perspectives. This also allowed reducing payback time of robotization of welding processes and promotes rise of welding robots application at small and medium-sized enterprises.

The modern welding robots are equipped with tracking (machine vision) systems. It allowed performing continuous monitoring and control of welding parameters. Integration of 3D visual control systems in robotic complexes for arc welding has got a widespread use.

Significant growth of income is predicted in a long-term perspective in a sector of arc welding robots, since they get more and more application in general machine building branches, where manual and mechanized arc welding is far more often replaced by robotic welding.

Today keeping profitability under conditions of price reduction for welding robots is a serious problem for IR manufacturers all over the world. Price becomes the main criterion for the clients in selection of welding robots since they try to decrease capital input. Robotics suppliers should have tighter contact with the developers of systems for automation of industrial processes and production in whole and create individual solutions in accordance with the requirements of end users.

In order to increase compatibility of the different components taking part in technological process of welding, the manufacturers of welding robots try to set a partnership with the suppliers of power sources and other welding equipment.

Today the flexible and adjustable robots, which are good for mixed and multipurpose production lines [13], are in more and more demand.

Continuous work on improvement and development of brand new IR designs allowed significantly amending technical-economical indices of IR currently proposed at the market. Table 4 shows an example of comparison of some technical-economical indices in IR designed by KUKA Company [11, 14].

In the conclusion it should be noted that commercial robots today are the key element for revolutionary transformations of production. IRs fulfil the functions, which have already exceeded the bounds of performance of repetitive tasks.

Table 4. Comparison of IR technical-economical indices from KUKA company, % (indices of 1980 are taken for 100 %)

Index	2000	2010 (Quantee series)
Primary cost of production	30	20
Weight	50	40
Number of parts	30	20
Time of assembly	20	15
Maintenance expenses	30	30
Productivity	200	300

New generation of IR differs by such purely «human» features and capabilities as brain, dexterity, memory, learnability and object identification. Reduction of sizes, rise of speedwork, decrease of IR price, on the one hand, and necessity in increase of quality, productivity and flexibility of manufacture have become the main factors of growth of robotics demand and expansion of its application range.

Robotics allow preforming a revolutionary change of process of commercial production, promote complex solution of the problems of quality improvement and rise of productivity, saving of physical, power and human resources at new technological level.

The present day application of robots is frequently the single correct variant to survive under competitive conditions of large-series as well as small and medium-sized enterprises. Application of commercial robots is not an exclusive right of only large industrial corporations and large-series groups of companies.

Today reasonable price and flexibility of design of robotic technological complexes allow using such equipment for organizing production of commercial flow lines as well as small and medium-sized enterprises.

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