

Industry 4.0 vs Welding Engineering

Abstract: The notion of Industry 4.0 poses a new challenge for various industries, including the widely defined welding engineering. Presently, we are witnessing the Fourth Industrial Revolution initiated in 2010. This revolution will significantly influence not only mass production of goods but our daily life as well. Many solutions related to the new industrial revolution will affect our reality in the years to come. To face these new challenges, welding engineering personnel will need to collaborate in interdisciplinary teams on a much closer basis to implement fusion welding, pressure welding and adhesive bonding technologies in industrial practice. Producers of welding equipment are already offering solutions constituting inherent elements of Industry 4.0. Only time will show the developmental direction of welding engineering. The study presents ideas behind individual industrial revolutions, the historical outline concerning the development of welding technologies, requirements which should be satisfied by personnel implementing and benefiting from Industry 4.0 as well as exemplary welding engineering-related solutions.

Keywords: Industry 4.0, Fourth Industrial Revolution, welding engineering-related solutions

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Introduction

The centuries-long technological development is responsible for the fact that lot production enables the making of products characterised by properties and quality acceptable by customers. The aforesaid development has also been accompanied by effort undertaken to reduce human labour input, decrease the negative impact on the environment, but primarily to reduce production costs, making products available for many users. Four industrial revolutions have been identified until today (Fig. 1). All of them significantly affected the organisation of work in companies as well as strongly

influenced the development of civilisation and the quality of our life.

The First Industrial Revolution

The first industrial revolution was symbolised by the steam engine patented in 1769 by a Scottish engineer by the name of James Watt. The obtainment of patent protection contributed to the widespread use of the steam engine (initially primarily in the textile industry in England). When the patent protection of James Watt's invention expired around 1800, in England alone there were about 5000 steam engines (and tens on the European continent).





			
1st industrial revolution	2nd industrial revolution	3rd industrial revolution	4th industrial revolution
mechanisation	electrification	digitisation	networks/ Internet
<ul style="list-style-type: none"> mechanical control (cams) steam engines 	<ul style="list-style-type: none"> punched cards for information recording first production lines 	<ul style="list-style-type: none"> microcontrollers controlling machinery development of automation IT systems in production planning and monitoring 	<ul style="list-style-type: none"> vertical and horizontal connection of components and machinery in networks based in Internet standards identifiable and communicable objects self-improving objects
INDUSTRY 1.0	INDUSTRY 2.0	INDUSTRY 3.0	INDUSTRY 4.0

Fig. 1. Industrial revolutions [1]

The first industrial revolution brought about changes not only in the textile industry but also in metallurgy, triggering the intensive development of a new means of transport, i.e. railway (since 1825) and, consequently, the development of a new sector of the heavy industry, i.e. the production of railway tracks and rolling stock. As a result, many production plants opened in the whole of Europe [2].



Fig. 2. Steam engine patented by James Watt [3]

The Second Industrial Revolution

In turn, the second industrial revolution was symbolised by the production line enabling the high-volume manufacturing, e.g. Henry Ford

factory (Fig. 3) as well as the possibility of generating and transmitting electric energy.

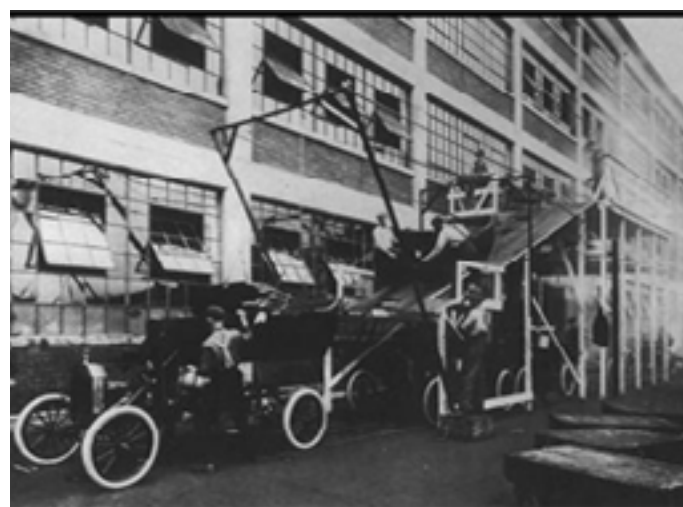


Fig. 3. Production line in Henry Ford's factory [4]

The second industrial revolution started in the middle of the 19th century and gave rise to numerous technical solutions. In 1852 a chemical engineer J. I. Łukasiewicz developed the oil refining method and made the first kerosene lamp in 1853. In 1879 T. Edison invented a light bulb. England saw the first electric trams on its city streets. In 1876 a Scottish scientist Alexander Bell invented a telephone, whereas in 1897 R. Diesel built the first combustion engine. In 1867 Alfred Nobel patented dynamite. Cars and

aircraft became increasingly popular. In 1903 the Wright brothers, Orville and Wilbur, made the first flight on a plane propelled by the combustion engine. The first vacuum cleaner was made [5]

The Third Industrial Revolution

It started with the implementation of programmable digital machines equipped with programmable logic controllers (PLC) (the first programmable logic controller was used in 1969) [6]. The third industrial revolution started in the late 1960s and early 1970s and was primarily concerned with science and technology. Actually, that revolution has continued incessantly until today. The third industrial revolution was connected with the digitisation of production, computerisation, the implementation of new IT solutions and the use of new energy harvesting sources. The revolution involved the automation of work as well as the development of telecommunications and transport. The major achievements of the third industrial revolution included the widespread implementation of transistors, integrated circuits, optical fibres and the generation of electric energy in nuclear power plants. The planning and monitoring of production involved the extensive use of IT systems. Increasingly many tasks were performed using computers, leading to the increased productivity in companies. Furthermore, the revolution saw the growing number of robots able to “collaborate” with humans. The

third industrial revolution also resulted in the development of services available via the Internet. It became possible to shop on-line, pay via the Internet and perform many other activities remotely. The most important inventions included a commercially available microprocessor (16 November 1971) and a microcomputer (1975), launched in 1977. The advent of Internet was responsible for the intense IT development in the late 1990s [5].

The Fourth Industrial Revolution

The fourth industrial revolution aims to increase the competitiveness of companies through the implementation of advanced solutions involving automation, robotisation and informatisation of production processes (CAx) characterised by high customisation (addressing customer's needs in a “personalised” manner) [8]. The revolution started in 2010, when Germany's Ministry of Education and Research (BMBF) initiated activities related to future advanced technologies and developmental trends, extensively affecting the society [9]. The aforesaid changes refer to all stages of product life, i.e. the initial concept, through the development, production order, manufacturing, delivery to the customer and recycling [10].

The fourth industrial revolution also referred to as Industry 4.0 is based on nine technological “pillars” [11], i.e.

1. Big Data – technology including ability to collect, store and analyse [on a predicative basis] enormous amounts of data, which can be used to identify imperfections and production process bottlenecks.
2. Autonomous robots – new generation of robots characterised by higher autonomy as well as ability to learn and interact with other robots and humans.
3. Simulations – operators and designers of systems can model and optimise machine settings in virtual reality, reducing the actual time of settings to a fraction of what was previously regarded as possible.



Fig. 4. First commercially available microprocessor Intel 4004 [7]

4. Integration of systems – use and making digital data available within the vertical area, limited by the management level and machine production. In addition, horizontal integration between suppliers of raw materials and suppliers of equipment can be beneficial for both producers and suppliers.
5. Internet of Things (IoT) – combining all built-in devices, production plants, offices and companies, becoming increasingly important in terms of making data available (on a real-time basis) between all elements of the system and all related parties.
6. Cybersecurity – in view of the unprecedented extension of industrial communication, cybersecurity has become an aspect of critical importance and significance.
7. Computing cloud – significant part of IoT communication and the communication of large-sized data will take place via the cloud, making the safety of the above-named operations a very high priority.
8. Additive manufacturing – 3D printing enables the production of small lots, fast design changes, the reduction of stock and lower transport costs (because of in situ production).
9. Extended reality – presentation of tasks for production personnel and technical service personnel will be more useful, making work easier and more efficient.

The proper implementation of the assumptions of Industry 4.0 will enable [11]:

- increase in productivity of 15-25%,
- decrease in machinery downtime of 30-50%,
- reduction of storage costs by 20-50%,
- reduction of a time needed to launch a new product by 20-50%.

The Fifth Industrial Revolution

A future (5th) industrial revolution is said to involve the development of robotics and the return of a human to the production process, where humans in conjunction with robots will be able to achieve significantly more than the

fourth industrial revolution [12]. The beginning of the new industrial revolution is exemplified by a game of “freestyle chess”, where a human and a computer play together versus another computer. Such collaboration between the human and the machine makes it possible to achieve better results than those obtainable by the computer alone. During the game, most decisions are taken by the computer, yet at a certain moment it is better to make a move different than that suggested by the machine and act independently. The human factor will continue to be a key element enabling the achievement of better results [13].

The ongoing fourth industrial revolution seems to be another significant challenge for companies as regards changes in production systems. The three previous revolutions introduced (chronologically) steam, electricity and automation to industry. When analysing the requirements of each industrial revolution in relation to which part of existing infrastructure and science park had to be replaced with new solutions to fully exploit the potential of a new leap forward in civilisation, it appears that the ongoing revolution will require the relatively small replacement, e.g. of machinery stock. Companies predict (on the basis of surveys conducted at 300 companies in Japan, Germany and USA) that between 40 and 50% of existing manufacturing base will be replaced by new solutions resulting from the implementation of Industry 4.0 (Fig. 5). As a comparison, related market research revealed that the implementation of technical and technological solutions of the Third Industrial Revolution, i.e. automation, required the replacement of up to 90% of machinery stock. Representatives of industry assume that during the fourth industrial revolution the primary requirement will include the retrofit of existing equipment by providing it with complex networks of sensors and new systems of communication. The implementation of assumptions of the presently ongoing industrial revolution will require

significant development and knowledge (particularly by departments responsible for the retrofit of industrial infrastructure) how to implement changes in machinery stock to adapt it to the needs of Industry 4.0. The replacement of production resources possessed by the company will be needed to a lesser degree than before [14].

Welding Engineering and Technical Development

When analysing changes taking place during successive industrial revolutions, it seems justified to refer those to welding engineering. Until 1880, joining methods, including welding, were primarily developed and used in craft workshops. The outbreak of World War 1 and that of World War 2 triggered the development and industrial use of both fusion and pressure welding processes (Table 1). Resistance, gas and arc welding processes were developed before the outbreak of World War I. At the beginning of the 20th century, gas welding and cutting were dominant technologies. The development of a gas torch in France in 1901 enabled the cutting of structural materials. However, the greatest development in welding engineering was initiated by the demonstration of carbon arc welding by Nikolay Benardos and Stanisław Olszewski in 1885. As a result, in 1904 Oscar Kjellberg developed manual metal arc welding. Afterwards, TIG, MIG, submerged arc MAG, electroslag and plasma

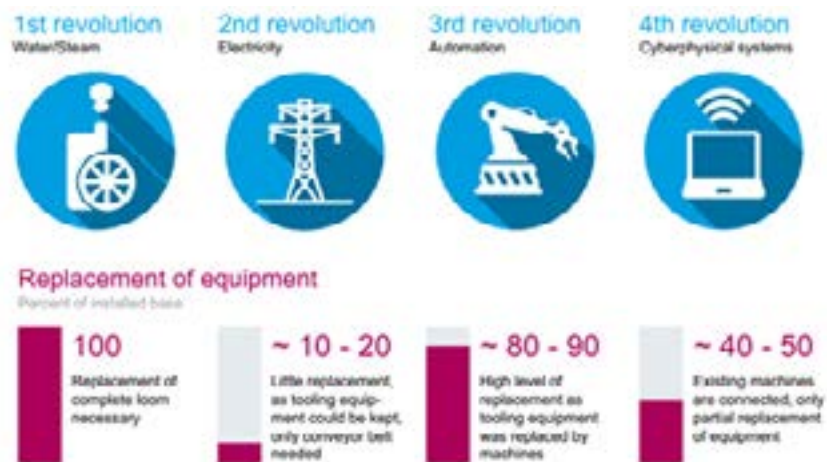


Fig. 5. Effect of industrial revolutions necessitating the replacement of equipment and machinery [14]

Table 1. Development of welding technologies

Process	Inventor	Year	Country	Remarks
Oxy-hydrogen welding	Robert Hare	1802	USA	
Carbon arc welding	Nikołaj Benardos Stanisław Olszewski	1885	Russia Kingdom of Poland	
Thermite welding	Hans Goldschmidt	1895	Germany	
Oxy-acetylene welding	Charles Picard Edmond Fouche	1901 1902	France	
Manual metal arc welding	Oscar Kjellberg	1904	Sweden	
TIG welding	H.M. Hobart P.K. Devers	1926	USA	
Submerged arc welding	D.A. Dulczewskij	1929	USSR	
Electroslag welding	B.E. Paton G.Z. Wołoszkiewicz	1949	USSR	[17]
MIG welding	P.K. Devers	1948	USA	
Electron beam welding	K.H. Steigerwald	1949	Germany	
Plasma welding	Robert M. Gage	1953	USA	
CO ₂ -shielded MAG welding	K.V. Lyubavskii N.M. Novoshilov	1953	USSR	[18]
Self-shielded flux-cored arc welding	A.A. Bernard	1953	USA	[19]
Laser-beam welding	Martin Adams	1970	Great Britain	
Hybrid laser welding	W.M. Steen	1977	Germany	
T.I.M.E. welding	John G. Church	1981	Canada	[20]
CMT welding	Manfred Schorghuber	2004	Austria	

arc welding processes were invented [15, 16]. The invention of electron beam welding in 1949 and laser welding in 1970 enabled the development of advanced joining technologies involving the use of concentrated energy beams. The recent achievements in welding technologies include low-energy processes (CMT, ColdARC and STT), invented primarily as a results of the development of IT and electronic systems.

The development of fusion welding technologies was accompanied by the development of processes enabling the pressure welding of metallic materials and, with the passage of time, plastics. In addition, the intense development of chemical industry has increased the significance of adhesive bonding processes in the welding sector. Presently, designers and technologists can choose among many solutions enabling the obtainment of fusion welded, pressure welded and adhesive bonded joints in relation to materials being welded, dimensions of a structure, required quality and running costs of a given technological solution. Some processes are performed manually, whereas some other within mechanised, automated or robotic systems. Regardless of solutions used in the future, highly skilled personnel will remain a core success factor.

Requirements for personnel

The implementation of solutions inspired by Industry 4.0 in a company requires the employment of appropriate technical personnel highly competent in IT systems and control systems. In addition, certain personnel skills and qualifications referred to below will be particularly important as regards production-related IT systems. It can be supposed that technological knowledge alone will be insufficient and welding engineers will need assistance of software developers, electronic engineers and automation specialists to a greater extent than today. Obviously, knowledge of materials engineering, welding technologies and structures will constitute the basis for the development

of technologies concerning the fusion and/or pressure welding of structural materials.

Based on the analysis of future tasks to be performed by qualified personnel in the smart factory of the future, it is possible to identify lists of various required skills and qualification varying in significance. To determine necessary priorities one can apply the “MuShCoW” prioritisation technique (MoSCoW) used in business analysis and when creating software aimed to reach an agreement among stakeholders in relation to the significance of each requirement and its satisfaction. The above-named method contains the following categories:

- MUST – (must be) describes a requirements which must be satisfied in relation to the ultimate solution,
- SHOULD – (should be) represents a high-priority item, which should be contained in the solution, where possible,
- COULD – (could be) represents desirable, yet not indispensable requirements to be satisfied in the future, depending on existing possibilities,
- WON'T – (will not be) represents a desirable yet unsatisfiable requirement (at least in the foreseeable future).

The above-presented workers' skills and qualifications needed in factories of the future are listed in Table 2. The analysis of abilities valuable in the future has revealed the growing importance of various technical but also personal skills and qualifications. As regards technical requirements, crucial competence includes IT-related qualifications, abilities to process information and data as well as to understand the organisation of production and other processes. Furthermore, abilities to operate and interact with advanced interfaces (human-machine) will be highly appreciated among qualified personnel. Because of the ubiquity of information and various process data as well the necessity of integrating various technological processes, workers will need to acquire skills related to knowledge management and an interdisciplinary approach

Table 2. Qualifications and skills of workers in factories of the future [22]

	Must	Should possess	Could
Technical qualifications and skills	knowledge and skills in computer systems and information technology	knowledge of management	knowledge of programming and information encoding
	skills in the processing and analysis of data and information	general knowledge of technologies and organisation (interdisciplinary knowledge)	specialist knowledge of technologies
	knowledge of statistics	specialist knowledge about production activity and processes	awareness of ergonomics
	knowledge of organisation and processes	awareness of cybersecurity and data protection	knowledge of legal regulations
	ability of use advanced method of communication (human-machine, human-robot)		
Personal qualities	self-management ability and ability to manage time	confidence in new technologies	
	ability to adapt to changes	positive approach to continuous improvement and lifelong learning	
	ability to work in a team		
	ability to collaborate in a changing cultural environment		
	communication skills		

to the understanding of organisation, processes and applied technologies. It will also be necessary to show appropriate sensitivity to cybersecurity and data protection. Technical skills, e.g. in relation to welding technologies will also be necessary, yet specialist knowledge of programming and information encoding – not so much. In-depth technical knowledge will no longer be indispensable, whereas more general knowledge of various areas of expertise will be perceived as an asset. Furthermore, the personal development of qualifications and skills, e.g. through management-oriented development will become important. Soft skills, such as ability to communicate with others, work in a team and self-management will become crucial for junior positions, e.g. welding machine operators. Presently, typical shop-floor personnel usually do not participate in training concerning the above-presented issues as their work does not require this type of involvement. However, in smart factories of the future a lot of emphasis

will be given to team work and ability to communicate within a team on a daily activity basis [21, 22].

Because of worker's greater responsibility and influence on the company operation, employees will need to learn how to manage their time and acquire general management skills. A worker in the factory of the future should have confidence in new technologies. In addition, such a worker will be aided by elaborate IT systems when searching for new solutions. Owing to the worker's full interaction with IT systems, tasks performed by personnel will represent very high quality. Another important aspect includes readiness for continuous self-improvement, e.g. through lifelong learning. The above-named approach applied across the board will enable the maintaining of the dynamics of changes within the organisation itself - in relation to production, logistics, design and research and development. An engineer in Industry 4.0 will be an open and active person

keen on diversity both in terms of contacts with other people and tasks to be performed. Furthermore, the above-named engineer will be able to present highly technical and/or detailed information in an enthusiastic and optimistic manner, winning over listeners to presented ideas. In addition, such a person will pay great attention to detail, strive after perfection, perform high-quality work and observe related standards, principles and procedures [21]. The extensive involvement of the entire personnel will translate into the more intense development of the company and benefitting from opportunities offered by the notion of Industry 4.0.

Based on the information presented in Table 2, exemplary requirements concerning operators of welding robots are the following [23]:

1. *Experience*

The operator should be aware that a properly developed and applied welding technology will ensure the obtainment of requirements adopted in relation to joint to be made and that failure to analyses changes and “going against the tide” may adversely affect the process of welding and, consequently, preclude the obtainment of a proper joint.

2. *Awareness of property and responsibility*

The operator should feel responsible for equipment operated by them.

3. *Initiative*

The operator should show the initiative aimed at quality improvement (particularly important when making complicated structures). For instance, the operator working on a TIG robotic welding station should ensure the quality of electrodes, maintain the stability of the filler metal wire feeding system and monitor the condition of fixtures and the store of spare parts.

4. *Thinking in 3D*

The providing of 3D visualisation facilitates the robot operator's work. The operator can follow the movements of the robot arm, particularly when making complicated structures and poorly accessible areas.

5. *Computer skills*

Computer skills and experience help the operator learn robot programming faster and use all available advantages offered by related software.

The Fourth Industrial Revolution in Welding Engineering

The fourth industrial revolution has also influenced welding engineering. It has become important not only to achieve assumed efficiency in production, but also to obtain appropriate effectiveness of the company in the global sense. Similar to previous industrial revolutions, companies unable to immediately adapt to the demands of the modern market will have to incur significantly higher costs in the future to meet the aforesaid requirements and keep up with the competition. According to a representative of Valk Welding [24], in view of the assumptions of Industry 4.0, welding engineering should be approached slightly wider:

- broader look – material joining technologies have always been developed using the “push forward” principle. However, recently it has been possible to observe a different approach i.e. “acquisition” through satisfying market needs. When implementing the notion of Industry 4.0 customers do not buy and store entire series of machinery, require customisation involving the satisfaction of specific requirements in terms of machinery size and technological parameters to be used during, e.g. the welding process. The processing of such orders requires an integrated supply chain, an increase in time of actual use of own resources and the reduction of downtime. In addition, manually entered corrections in software, positioning and exchange of tools are limited.
- intelligent robots and additional software programmes – robotics, particularly expanded sensory networks, offer increasingly advanced and innovative solutions. Another approach involves the more extensive application of “off-line” programming principles, i.e.

outside the production line, without the need of stopping ongoing production processes. The use of virtual reality is very useful in this scope in the following manner:

- welding programmes as an element of the entire production – the creation of automated production systems enabling the automated performance of welding processes based on technical and 3D documentation (using database about materials, dimensional changeability, dimensional tolerance etc.), without using operator's expertise. This future, i.e. where the robot analyses structures and single-handedly adjusts technological welding conditions is "just round the corner". Software programmes enabling the optimisation of welding parameters by robots during the process are already available. To fully benefit from ideas behind Industry 4.0, welding programmes will have to be integrated into "smart" production processes adapting to changes taking place in production lines, e.g. by changing the product itself (dimensional tolerance, length and thickness of individual elements etc.). Changes will be entered on the basis of dimensions measured during the welding process or at the preparation stage, within an automated cycle.
- task of welding software provider – particularly important is awareness concerning the proactive co-development of software programmes enabling the fixing of systems, the monitoring of processes and production management comprehensively addressing target customer's visions. Companies implementing the notion of Industry 4.0 wish that welding system supplier provide the former with complex solutions enabling production at lowest expense, yet meeting appropriate quality-related requirements.

In terms of requirements concerning production personnel and assumptions of Industry 4.0, the opening of a "smart factory", less worker-dependent, requires that necessary welding engineer's expertise be digitised in a manner

enabling computers to make proper decisions, comparable to those taken by the welding engineer in the traditional system. In addition, the welding equipment must be provided with microprocessors and various detectors transforming welding-related information into digital data. The aforesaid data must be effectively and efficiently sent over various distance, often exposed to strong electromagnetic fields. Companies must possess appropriate technical resources to store significant amounts of generated data without compromising cybersecurity [25]. During previous revolutions, manufacturers focused on the development of welding power sources as well as fusion and pressure welding machines. Industrial Revolution IV gives more emphasis to digitisation, control systems and data transfer.

Global concerns are already offering their customers state-of-the-art welding solutions falling within the notion of Industry 4.0, e.g. fusion and pressure welding machines as well as monitoring systems. In 2013 Fronius launched a new line of welding machines named TPS/i (Fig. 6), equipped with high-performance processor and a superfast busbar. As a result, users can send more data in shorter time. In addition, the company has developed a system for



Fig. 6. TPS/i welding machine (Fronius) [27]

documenting and analyse data (WeldCube), a system facilitating welded training (Virtual Welducation) and a WeldConnect software programme [26].

Sirius Electric has launched an ultrasonic welding machine (Fig. 7) equipped with a module of remote support via router, enabling the remote software administration and control. It is possible to connect the welding machine control system with a personal computer inside the company, connect the system with the company's LAN and perform remote monitoring and modification of welding machine parameters.

ABICOR BINZEL has addressed the needs of Industry 4.0 by offering a system enabling

the management of welding gases (Fig. 8). The aforesaid solution makes it possible to reduce the consumption of shielding gases, decrease welding costs, lower the emission of CO₂, perform the calibration of the gas flow adjustment system and record measured values.

Summary

When looking at changes occurring in production systems it can be assumed that the greatest challenges are still ahead. The notion of Industry 4.0 requires educating new engineering personnel characterised by narrower expertise but able to integrate very many areas of technique in production systems and, at the same time, aware of sociological issues, social culture and changes taking place in today's world. There are many indications of future ubiquitous machine intelligence resulting in the gradual disappearance of the barrier between the human and the machine.

The widely defined welding engineering sector is also undergoing significant changes in technologies but also in terms of personnel's mentality. Today's welding engineers, highly competent in fusion welding, pressure welding and adhesive bonding technologies will have to cooperate considerably closer than before with engineers of other sectors to successfully implement the concepts of Industry 4.0 in their own production organisations. The development of a fully useful joining technology will be an indispensable element of production, yet integration into an entirely complex system is likely to be tasked with engineers 4.0.

Many global companies are already offering their customers solutions inspired by ideas behind Industry 4.0. The aforesaid solutions are independent, yet most importantly, they can be integrated into larger systems including advanced welding equipment, monitoring systems and software. Once adopted by industries the above-named solutions will translate into technological achievement and economic benefits.



Fig. 7. Ultrasonic welding machine (Sirius Electric) [28]



Fig. 8. Shielding gas management system (ABICOR BINZEL) [29]

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