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Original scientific paper

INFLUENCE OF INDUSTRY 4.0 IN WELDING ENGINEERING – THEORETICAL APPROACH –

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A b s t r a c t: Today we are involved in the fourth industrial revolution which aims towards autonomous working smart factories operating in smart manufacturing of smart industry. In this paper is discussed about Industry 4.0 and the influence of this new technological revolution in welding engineering. Smart factories are aiming for smart production using humanles and paperless technologies and accordance to that is analyzed the influence on welding engineering. Interconnectivity among welding power sources, software, and manufacturing decision-makers makes possible the integration of Industry 4.0 in welding environment. Working together with the "Internet of Things" and "Industry 4.0" the possibility for implementing sensor technology to provide real-time welding process monitoring and high-quality production has been met.

Key words: Industry 4.0; welding engineering; weld monitoring

ВЛИЈАНИЕ НА ИНДУСТРИЈАТА 4.0 ВРЗ ЗАВАРУВАЊЕТО – ТЕОРЕТСКИ ПРИСТАП –

А п с т р а к т: Денес сме инволвирани во четвртата индустриска револуција која се стреми кон автономни паметни фабрики кои работат во паметно производство на паметна индустрија. Во овој труд е дискутирано за Индустријата 4.0 и нејзиното влијание врз заварувањето. Паметните фабрики се стремат кон паметно производство користејќи технологии без луѓе и хартија и соодветно на тоа се анализира влијанието врз заварувањето. Меѓусебната поврзаност на изворите на енергија за заварување, софтверот и одлуките поврзани со производството го овозможи интегрирањето на Индустријата 4.0 во областа на заварувањето. Заедничкото користење на "Интернет на нештата" и "Индустрија 4.0" ја отвора можноста за имплементирање на сензорната технологија во следењето на заварувачкиот процес во реално време, а со тоа и задоволување на потребата од завар со висок квалитет.

Клучни зборови: Индустрија 4.0; заварување; мониторинг на завар

1. INTRODUCTION

This paper discusses about the technological industrial revolutions especially about the fourth industrial revolution and its emphasis on welding engineering. All of the industrial revolutions are defining the process of change from a handicraft economy to one dominated by industry and machine manufacturing. These technological changes introduced new ways of working and living and fundamentally transformed society. Every industrial revolution indicates the technical progress of industry.

Welding presents a major joining process in modern manufacturing, primarily used for the creation of metal structures and components, as well as maintenance and repair operations. It is playing a significant role in manufacturing, especially in industries that use complex metal components and structures.

Until now, little importance has been given to Industry 4.0 and its impact on welding engineering. Recent developments in welding engineering have shown the need for an automated weld monitoring system and as result of that it brings digital connectivity to the welding engineering. The role of the automated weld monitoring system is to deliver a diagnosis of weld quality, so needs to be able to track welding parameters: current, voltage, gas flow rate, wire feed speed, and take multiple measurements every second. Using patented algorithms to analyze the real-time welding data, modern weld monitoring measurement systems can detect when a problem arises [1].

2. REVIEW OF THE INDUSTRIAL REVOLUTIONS

The historical timeline of technical progress is presented in Table 1 [2]. All these four revolutions significantly affected on the organization of work in companies and influenced on the development of civilization and the quality of peoples life.

T a b l e 1

History of technical progress [2]

Industrial revolution	Time period	Technology
First	1784 – mid 19th century	Water and steam – powered mechanical manufacturing
Second	Late 19th century – 1970s	Electric – powered mass production based on the division of labor (assembly line)
Third	1970s – today	Electronics and information technology drives new levels of automation of complex tasks
Fourth	Today	Sensor technology, interconnectivity and data analysis allow mass customization, integration of value chains and greater efficiency

Industry 1.0 was established in England at the end of the 18th century and mid of the 19th century, to 1840, and is related to the mechanization of production and vast usage of steam power. The revolution impacted the textile industry, mining and agriculture marking the first major transition from handicraft economy to one involving the use of machines in the manufacturing processes.

The second industrial revolution (2.0) began in the late of the 19th century, around 1870s, also known as the "Technological Revolution Era", involving industrial processes that used machines powered by electrical energy. In this second revolution Henry Ford, known as the father of automotive mass manufacturing, was the first to bring the idea of mass production. Starting from using conveyor belts for pigs to implementing these principles into the production of automobiles and creating a system where all vehicles are produced step by step on a conveyer belt.

The third industrial revolution started in 1969 where programable logic controllers were implemented on programable digital machines [3]. Start of digital revolution that marked the history of humanity. This revolution period introduced digitalization of production, computing devices and the use of new energy harvesting sources.

The fourth industrial revolution was initiated with its official use in 2011 as a name for a digital manufacturing project at the Hannover Messe, and today we are witnessing this Fourth Industrial Revolution. The fourth industrial revolution, also known as Industry 4.0, indicates the present phase of technical progress as a result of progress in information technology.

These technological revolutions and the transition from one period to another did not happen suddenly. In the second half of Industry 3.0 the progress of artificial intelligence is noted which is integral part of the following Industry 4.0 as a foundation for entering in the next technological industrial revolution.

3. INDUSTRY 4.0

The most used technical terms in the past years as "Internet of Things" and "Industry 4.0" are defining the new industrial revolution. The Industry 4.0 aims towards autonomous working smart factories and this is done by equipping almost everything with information and communications technologies of modern PCs. The last step is to connect them to a cyber-world, the internet. With the IoT all the manufacturing informations are stored in cloud. Intelligent software tools manage and control manufacturing processes and organize the supply chain. The end product will be produced on demand by additive manufacturing [4].

Production tools and manufacturing equipment as physical objects need to be digitally connected with the virtual world. Bauernhansl *et al*. [5] identified three key areas which will raise the economic benefit:

– The use of IoT and the digital services within the whole value chain.
– The change in hardware design from mechatronic to cyber-physical systems to make a comprehensive industrial-based network possible.
– Data generation, real-time “Big Data” analysis and development of prediction models for optimization control systems within the value chain.

The new fourth revolution gives the foundation of “smart factory” where we are witnessing the transformation from manufacturing industry. Not only automation and data exchange in manufacturing technologies, but beyond that, it is oriented towards the chain between the end points, including storage, logistics, recycling, energy systems, etc. With the implementation of cyber-physical systems, intelligent networks, intelligent logistics promote the establishment of smart factories operating in smart manufacturing of smart industry.

Industry 4.0 is based on nine technological pillars (Figure 1) [2] and aims to creation of digital production companies based on humanless and paperless technologies.

Fig.1. Technological pillars of Industry 4.0 [2]

On Table 2 are given nine technological pillars of Industry 4.0 and how they are implemented in this new era of the fourth technological revolutions.

Table 2

Technological pillars of Industry 4.0 [2]

Autonomous robots	Autonomous, cooperative robots, intelligent operation, standardizes interfaces
Simulation	Simulation of value networks, optimization of real-time data originated from intelligent systems
Horizontal and vertical system integration	Complete enterprise data-integration based on data transfer standards, preconditions for establishing a fully automated value chain (from the supplier to the customer, from management to the workshop)
The Industrial Internet of Things	The network of machines and products, multidirectional communication between the network members
Cyber-security	Operation in networks and open systems, organizing intelligent machines, products and system into a network
Cloud based systems	The management of large amount of data in open systems, real-time communication between manufacturing systems
Additive manufacturing	3D printing for producing prototypes and individual components
Augmented reality	For maintenance, logistics, various standardized operation processes, display
Big data and analytics	The full evaluation of available data, the support of real-time decision making and optimization.

As a result of manufacturing automation, better utilization of assets and efficient stock management is reduced manufacturing time and is noted growth of productivity. With the implementation of robots is expected improvement of flexibility and with real-time quick interference in case of errors with the help of advanced sensor technology and artificial intelligent is improved quality. Thanks to the advanced simulation devices and solutions efficiently fulfilling to the customers needs is reduced the lead time between plans and their realization [6].

4. INDUSTRY 4.0 IN WELDING ENGINEERING

The fourth industrial revolution impacts also on welding engineering. One of the developments in Industry 4.0 is the robotization of welding by implementing sensor technology, application of artificial intelligence, the development of standardized robot interfaces, interface for open-source programming, remote diagnosis via the Internet, maintenances, intelligent forecast of the need for part replacement [7]. Industry 4.0 represents "smart factories" where industrial welding robots are connected to a network and exchange information to improve their work. In Industry 4.0 are implemented cyber physical systems, systems that can connect the digital world with the physical world and optimize results thanks to continuous data analysis.

Welding parameters must be digitalized, and that means that welding machine needs to be equipped with hardware and software that will play the key role of the welding machine. This will arise ultrahigh speed data communication within the welding machine, but also the internet and the development of strategies for securing data and cyber-security. The influence of all four industrial revolutions on welding is shown on Figure 2 [12].

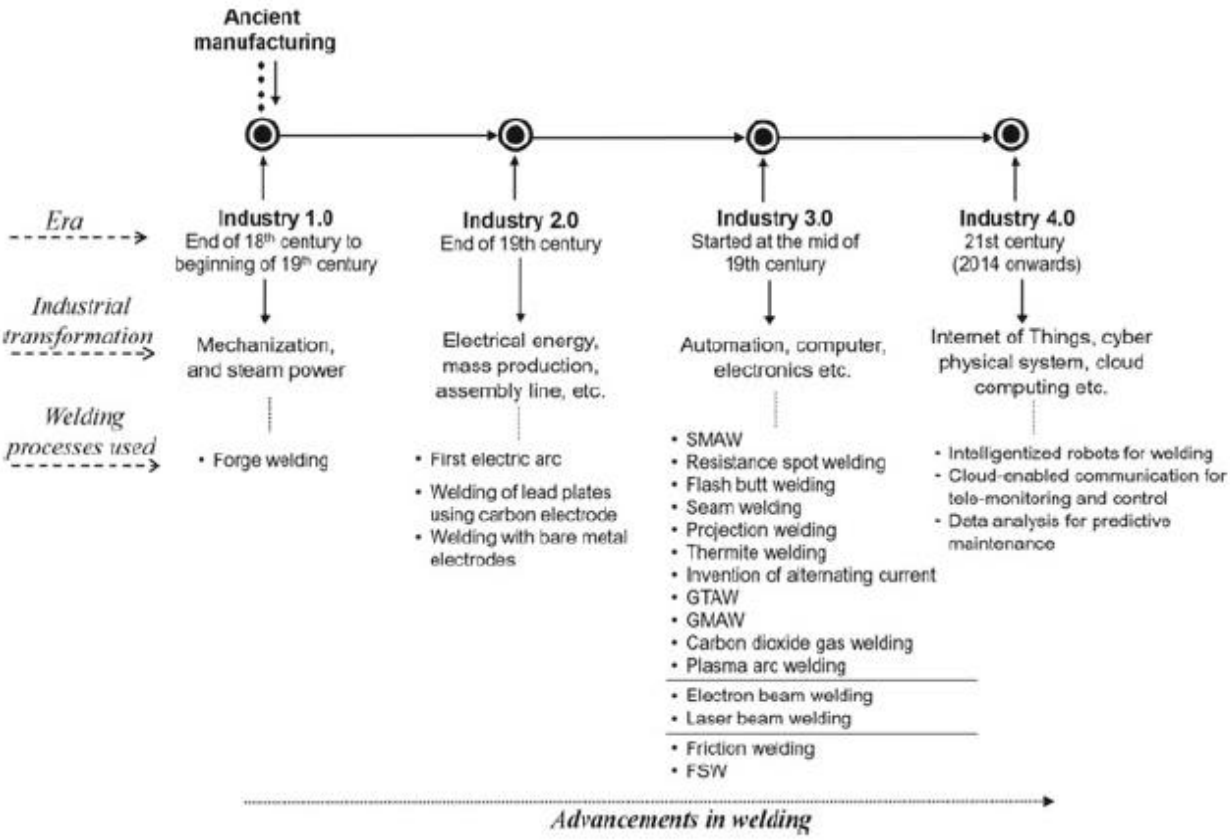

Fig 2. Evolution of technological revolutions and welding [12]

The developments of welding equipment influenced by Industry 4.0 contributed to the improvements in welding environment. Working together with the industrial internet of things and the cloud-based systems for data transfer, the following benefits can be observed: guaranteed and increased quality, increased productivity, cost reductions, management [8].

Interconnectivity among welding power sources, software, and manufacturing decision-makers makes possible the integration of Industry 4.0 in welding environment. The connection between intelligent power sources, robots, data collection, storage systems and weld monitoring software need to be integrated together so that can define the whole welding process. The software needs to track the whole welding procedure specification: wire feed speed, amps, volts, weld duration and heat input, and the monitoring software needs to record the prescribed welding parameters. The software for welding machines is designed to increase welding efficiency whether is done by a robot or a human operator. By implementing Industry 4.0 all the human experience and the knowledge needs to be digitalized, between material selection, welding procedures, interaction with the heat source, metallurgy and joint properties. The welding machines need to be equipped with powerful microprocessor where the electronics will have to operate in a very harsh, dirty and dusty industrial surrounding.

The control of welding parameters needs real time response and powerful hardware. The use of real-time monitoring allows avoiding defects and producing high quality joints. To illustrate, the use of arc sensors in GTAW system with automatic voltage control system is shown on Figure 3 [9]. The arc sensor controls the arc length with an automatic voltage control system as it can measure the position of the electrode over the joint groove.

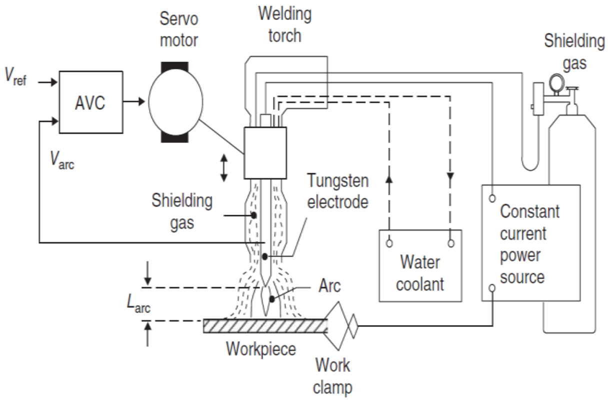

Fig. 3. GTAW system with automatic voltage control system [9]

When discussed about weld monitoring system, optical sensing systems have been developed to monitor and sense welding processes. One system that uses optical sensors is the stroboscopic video camera system (Figure 4) who can capture a video image from the process and it is designed for high temperature conditions such as welding processes. The stroboscopic video camera system consists of a laser unit, camera unit, and system controller [10]. The system can measure a two-dimensional weld pool boundary. Figure 4 shows the designed measurement system diagram, where the camera observes the weld pool at an angle to the direction of the weld and the laser is projected in the opposite direction [10].

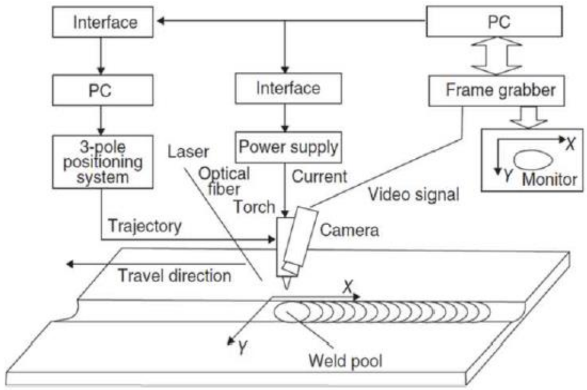

Fig. 4. Stroboscopic video camera system [10]

Another method is the ultrasonic technique in online weld monitoring for monitoring the welding process in real time and determining the weld joint penetration and joint tracking. On Figure 5 is shown the weld pool depth measurement using two shear wave probes asymmetrically disposed around the electrode center line. On Figure 5 is also given schematic diagram of the signals generated due to ultrasonic beam spread, where A is the penetration control signal, B is joint tracking signal, and C is the possible quality indication signal [11].

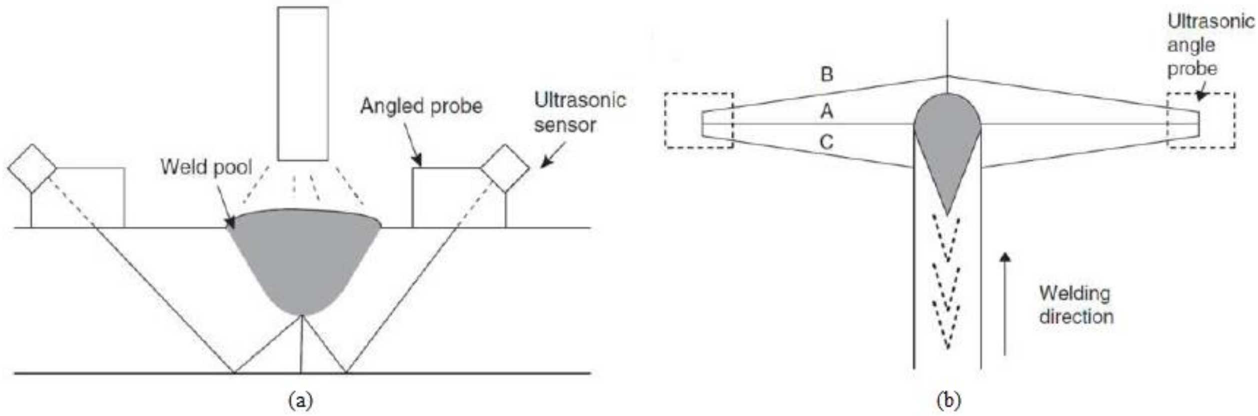

Fig. 5. Ultrasonic method for online weld monitoring [11]

With the ultrasonic method can be detected all existing welding defects in real time by a multifunctional ultrasonic sensor at real welding speed. The technology provides a real non-contact and remote access approach for real-time welding monitoring which plays an important role in development the next-generation intelligent welding machine [1].

In Industry 4.0 a step forward is done with automation of friction stir welding processes by utility of data in online process monitoring and control. The data from the welding process is used for online prediction of weld quality and control of the weld, presented on Figure 6 [12]. With implementation of the pillars of I4.0 to friction stir welding a weld quality can be predicted: tensile strength of the weld in real time and control of quality. For all the quality measuring parameters are used different signals so the utilization of sensors and proper signal processing techniques is the foundation of implementing Industry 4.0 in welding processes.

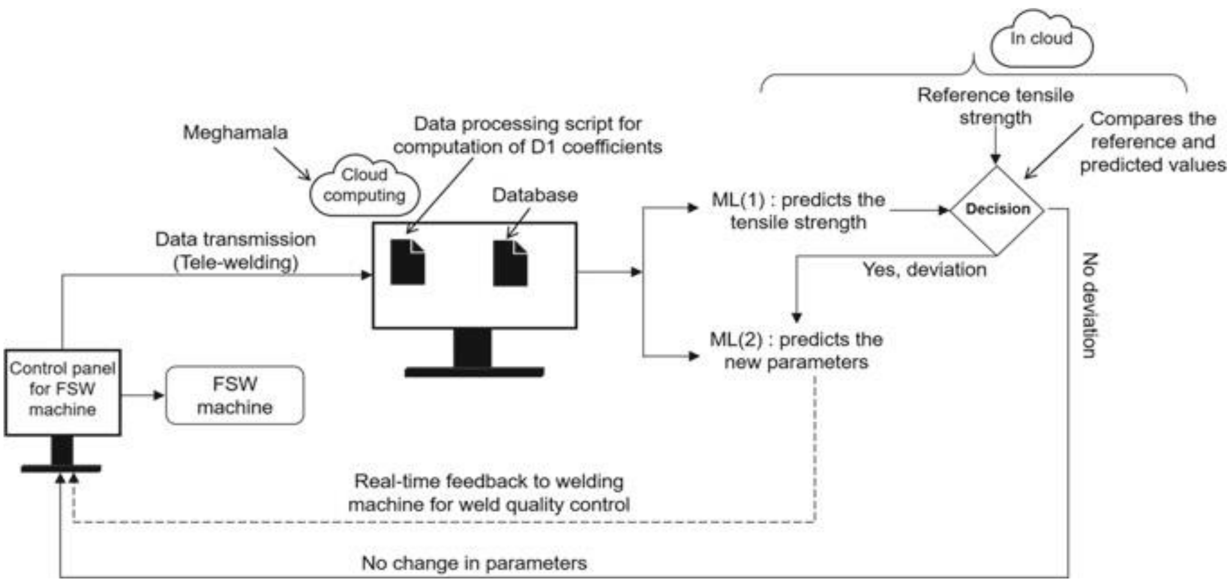

Fig. 6. FSW schematic diagram for real-time weld quality prediction and control [12]

5. CONCLUSION

The fourth industrial revolution has influenced welding engineering. It has become important to achieve efficiency in production, transparent planning, quality management, final costing, and effectiveness of the company. By intelligent weld monitoring the factory will provide documentation of the welding parameters, real-time parameter monitoring on the welding machine, and precise specifications from component management. With the weld management a consumption values for power, shielding gas, welding consumables and welding time are recorded to recognize potential savings and can influence on cost reductions.

The impact of Industry 4.0 in welding engineering is resulting in advanced welding technology helping factories to improve their efficiency and productivity. Advanced welding technology plays an essential role in creating lean manufacturing processes. It is important not only to achieve efficiency in production but also to obtain appropriate effectiveness of the factory. With the right type of technology, it can be eliminated workflow delays and duplications and accelerate entire processes through the automation of individual tasks.

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