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Industry 4.0 in welding

Abstract: To reach the next developmental stage of welding technologies, i.e. the implementation of the Industry 4.0 concept and the Internet of Things (IOT) in welding, it is crucial to understand and provide the welding responsible for technological development with necessary data; the objective being the facilitated obtainment of necessary machine data in future. The foregoing necessitates the development and adaptation of modern welding equipment to needs of the smart factory as well as to collect and evaluate a considerable amount of data relevant to welding processes. This paper presents a short overview of already available possibilities and ideas enabling the adaptation of today's solutions to the needs of Industry 4.0. in future.

Keywords: industry 4.0, welding, internet of things

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If it comes to discussions about the next level of industrialization, "Internet of Things" and "Industry 4.0" are frequently used buzzwords. The common vision of both, very frequently used terms is basically the use of locally generated data in a much greater context. The amount of locally generated data is strictly increasing due to the ongoing digitalization in all parts of our daily life. The combination of data from different sources enables the recognition of far-reaching dependencies and thus the establishment of essential improvements or even new features. When it comes to manufacturing technology, the different steps from data generation to data engineering and finally data analytics supply valuable information - for instance maintenance information or general plant status. In this context such information can be used to introduce overall optimization measures which should finally lead to increased productivity, less defective work and more efficient use of resources. Such added value for the customer is the driving force behind all ongoing activities in Industry 4.0.

In order to make this Industry 4.0 vision a reality, it is necessary to give each device, i.e. manufacturing equipment, sufficient skills in form of computational and communication technologies (ICTs) to enable local data acquisition, pre-processing and communication. A further goal of Industry 4.0 is to realize highly flexible, autonomously working and networked manufacturing cells and plants. All information required for production is obtained from networking, and special software systems manage the logistics, manufacturing, production and machine control. For the networking of individual plants, globally available cloud technology represents a promising option. Due to these measures in the field of production technology, products will be manufactured in much shorter time from order to delivery.

All of these activities pose great challenges, as well as opportunities, for welding technology

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and in particular for developers of welding equipment. Welding solutions must be available in digital form and efficient information and communication technology must be integrated into the welding equipment. These demands are especially pronounced wherever real-time requirements must be met. Furthermore, tailor-made software solutions running on welding power sources and central servers are required to enable end users to efficiently use the newly acquired features.

Another critical issue, somewhat neglected by many proponents and promoters of Industry 4.0, is the fact that the networking of systems always entails security risks. Accordingly, modern data and communication security concepts must be used in order to provide protection for the networks of production facilities.

Finally it has to be pointed out that in future virtual welding will evolve away from welder training to become an indispensable tool allowing to pre-fabricate the production of individual pieces in the virtual world.

Internet of things & Industry 4.0

What will be the main technological developments in the coming decades and how will they affect our lives? An exciting question that is hard to answer. "Internet of Things (IoT)" and "Industry 4.0 (I4.0)" are currently probably the most commonly used terms when discussing trends and visions regarding the next degree of industrialization and the "factory of the future". IoT and I4.0 are to be seen as synonyms for the worldwide technical advancement, which could become reality based on the current state of knowledge in the next decades [1, 2].

On closer analysis of these visions, it becomes obvious that this approach is based on the digital networking of all technical devices from computers to smartphones to automobiles to machines to production facilities and so on. In light of this Industry 4.0 can be seen as more of an evolutionary process, rather than a revolutionary one. The conversion of analogous objects entities (e.g. signals, processes, physical things) into digital representations, the so-called "digitization", is a mandatory prerequisite for this concept to happen.

The economic potential lies less in local data than in the intelligent evaluation, analysis and above all combination of the data carried out by tailor-made software tools in the field of supply chain, manufacturing, predictive maintenance and in the integration of the customer in the value chain. Saving potential of up to 70% is forecast [3].

A necessary requirement for this, however, is that this data must be made available via a digital communication network, even in real-time in certain cases. The digital connection of physical objects such as production tools and machines with the virtual world is seen as the most important innovation driver. Essentially, there are three key elements that are responsible for the economic benefit [3]:

- The integration of digital services into the entire value chain
- The change in machine development from mechatronic to cyber-physical systems to enable a comprehensive, industrial network
- Data acquisition and real-time analysis of large volumes of data and the development of predictive models for quality assurance within the value chain.

Currently there is still a big discrepancy between the real, physical world and the digital, virtual world. For example, many properties of products, such as material behaviour, degree of wear and tear, but also application and environmental conditions, have not yet been digitized and are not available per default in the virtual world. Therefore, it is also an aim of Industry 4.0 to digitize all possible information about products and things that are currently not available. This information can then be provided to a much larger group of experts as for example software service providers, analysts and control engineers. These experts can use this data, gathered from the permanent networking, for the user to generate added value, usually in the form of tailor-made software tools. In the future, therefore, the focus will no longer be on the sole technical advantage of the product, but rather on the ability to network and the associated benefits for the customer. Technical product innovation will increasingly be realized through the merging of different individual systems via digital communication channels and thus in a network.

The basis for Industry 4.0, as already mentioned, is the digital transformation of all information and knowledge. In products and production processes, this digitization is carried out by electronic sensor systems that map physical quantities such as temperature, distance, brightness, humidity, etc. to digital signals. The need to obtain all required information in digital form, in order to generate added value from it, will thus massively increase the need for sensor systems and digitized expert knowledge.

Already at this point it can be noted that all these activities generate a plethora of data, which in turn requires innovative solutions in data processing and storage. A promising solution for this is the use of large data processing centres, which can be accessed worldwide via the Internet. Such, so called, cloud systems have virtually freely scalable resources in terms of storage capacity and processing power. Furthermore, these systems are professionally managed and thus offer high availability. Currently, however, commercial end customers often refrain from such systems because there is significant doubt about the sufficient protection of the data against unauthorized access.

Another challenge still to be solved for the commercial use of cloud systems lies in the communication speed of the Internet on the user side, since ideally the data must be generated, stored and processed in real-time. This also explains the current efforts of states and telecommunications companies to expand the digital networks in order to enable ever faster data transfer.

In addition to ethical and legal aspects, which entail comprehensive data generation, storage and analysis in terms of user transparency, there are other key points to consider:

- Since every Industry 4.0 product generates and communicates digital information, it is necessary to standardize communication protocols in a uniform and efficient manner.
- This standardization not only has to ensure that the data exchange works in production networks or over the Internet, but that it is also secure. In this context, secure communication is understood to mean the following:
  - The transported data reaches the recipient in time,
  - The data may not be modified by unauthorized persons,
  - The data may not be read by unauthorized persons.

Product data is particularly sensitive because it provides information about all areas related to the product: manufacturer and user information, manufacturing conditions, quality and operating conditions. Basically, the user of a networked Industry 4.0 product enters into a relationship of trust with the manufacturer, which must not be jeopardized. Abuse of the data obtained must be prevented by all available means. Despite this challenge in terms of security, the networking of products also offers manufacturers a huge opportunity. These can directly observe the product and usage behaviour of the customer and derive knowledge for new product innovations - basically a win-win situation. In addition, the cost of accessing the Internet and using software tools, which work automatically or autonomously, must remain low, otherwise a lack of widespread user acceptance may be a likely result.

Industry 4.0 & welding

The consistent implementation of Industry 4.0 also has a decisive influence on the "factory of the future", which will develop into a "smart factory" [4, 5]. For a "smart factory" to work more or less autonomously without human interaction, some criteria must be met for welding applications:

– The welding know-how has to be digitized and prepared in such a way that a computer can make similarly correct decisions as an experienced welding technologist.
– The welding equipment must be equipped with high-performance information and communication technology and customized sensors so that all production-relevant information can be digitized and given the necessary real-time behaviour of the system.
– The need to transfer and store large amounts of data requires powerful network infrastructures and sufficient storage capacity.

Concepts for data and communication security must be created and implemented. This will change the core business of a welding power source manufacturer:

– In the early stages of welding technology the development was focused on the intensive examination of the direct conversion of electrical energy from the grid into suitable welding currents and voltages.
– In the 1990s, the full digitization of the welding process and its digital control became the main topic of innovations.
– Current welding systems have ultra-fast machine-internal and external data communication channels, high-resolution real-time control, the ability to store large amounts of data, IT security and intelligent human <> machine or machine <> machine communication.
– In future fully automatic welding systems will independently and without human intervention organize the production of new parts and access the wide experience in the central storage systems.

However, as long as the digitization process in welding technology is not completely completed, humans will continue to play a central role in determining welding solutions. Accordingly, the communication channel between human <> welding machine will continue to be one of the most important success factors.

Digitized welding knowledge

A networked, modular welding cell must be equipped with the right welding parameters and welding consumables, depending on the task assigned by the production control. Nowadays the welding technologist holds responsibility for the right choice of welding parameters. If these tasks are to be supported by intelligent software systems in the future, it is necessary to digitize existing knowledge and make it automatically retrievable. This is probably the most difficult challenge of Industry 4.0 in welding technology, as all the existing knowledge is very difficult to quantify and therefore hardly comprehensible to digitization [6]. For autonomous cells, however, digitized knowledge is a prerequisite. In addition, digital information about the component, the filler metal, the protective gas, etc. is necessary in order to be able to determine an optimal set of welding parameters automatically. At this point, the integrated networking of the "smart factory" must be effective and all information has to be available at the right time.

Modern welding power sources

Modern "Industry 4.0 ready" welding systems consist of several microprocessors networked by means of bus systems and thus already form a network internally. This architecture allows flexible implementation of a variety of system configurations with relatively few different base devices.

Basically, such power sources are clusters that perform the following tasks in the case of MIG/MAG applications:

– Processing of digital welding parameter characteristics.
– Realization of the resulting target signal curves for current and voltage at the arc.
– Welding data acquisition and local storage of

recent data records
- Automatic limitation of the welding power as a function of the permissible load capacity of the connected hardware components
- Provision of networking capabilities for cable networks (e.g.: Ethernet), wireless networks (e.g.: Bluetooth) and near field communication (e.g.: NFC)
- Self-detection and self-diagnosis of installed components such as welding torch, cooling unit, display and wire feeder, etc.

To meet all these requirements, welding equipment consists of transformers with ferrite cores, power electronics components, copper cabling for the supply and management of the welding current and various electronic control prints, which are connected via digital interfaces. Thus, a welding power source is a complex power electronic device that must not negatively affect itself nor adjacent systems in any operating condition via electromagnetic interactions. In addition, the sensitive electronics must be reliably protected from the harsh, dirty and dusty industrial environment.

To ensure this, innovative production engineering concepts are necessary, which also have to be checked in intricate functional tests (Fig. 1). But these tasks, which represent a major challenge in the development of modern welding power sources, are absolutely necessary to ensure the functionality of the system for the customer.

Fig.1. Testing the electromagnetic compatibility of a modern welding power source

Data communication

One of the key words in "Industry 4.0" is obviously "communication". But what does communication mean when it comes to welding? In the case of modern MIG/MAG power sources, the necessary in-machine communication can be estimated by a simplified calculations.

Modern short arc processes, such as CMT [7], operate at a droplet stripping frequency of up to 150 Hz, which means that one drop is removed approximately every 7 msec. In order to optimally control this drop removal by changing the current and voltage signal, it is necessary to intervene in the welding circuit 50-100 times during a drop separation cycle. This results in a remaining communication time between the arc and the control computer of about 30μsec. During this interval a lot of signal processing steps have to be carried out:
- The physical data must be digitized and sent to various microprocessors.
- All necessary computations to determine the right control action must take place.
- Finally all the derived control signals are sent back to the systems actuator.

All these real-time demands concerning the data transfer and signal processing represent an enormous technical challenge. To overcome this it is useful to distinguish between the internal data communication, on which the entire control technology is based on, and the external data communication via Intranet and Internet, which is mainly used for documentation purposes. Both networks meet completely different requirements in terms of real-time behaviour and data transmission rates.

Welding parameter selection & data storage

One of the most challenging goals of Industry 4.0 is the flexible, autonomously working manufacturing cell, which consist of different, but closely networked individual subsystems. In order to work autonomously, the manufacturing cell must be able to identify the blanks of the product to be manufactured and the product order. With reference to this component, the individual systems are then instructed and, in the case of the welding system, the welding parameters are transmitted. During the ongoing welding process, these are checked and, if necessary, corrected. For this purpose, as already discussed, a modern robot welding power source with powerful microprocessors, real-time data communication and appropriate control algorithms is necessary. The upstream selection of a welding process and corresponding welding parameter characteristics depending on the base material, sheet thickness, layer structure and possibly gaps is independent of the production welding and can be performed by an assistance system, e.g. be adopted as a cloud application or at least supported. Of course, this process can only work if the necessary welding knowledge has been digitized accordingly.

Since the welding process is classified as "special process" according to the ISO 9001 definition and very domain specific knowledge is required to solve a concrete welding task, it will take a long time before appropriate knowledge management systems are established. However, welding data storage is already becoming more and more interesting to the user - not just for documentation, but also for data analysis with regard to possible defects in the welded joint and for intelligent, predictive wear part management. Since, however, it has not yet been precisely evaluated at which level of detail the data must be available for the creation of appropriate algorithms, there is currently a strong tendency on the user side to record and store the data at as high as possible resolution. Since the Internet connection speed is often insufficiently at customer sites and the topic of data security on cloud systems has not been finally clarified, such production data can also be stored and analysed locally. Specially designed server systems with coordinated system performance and intelligent evaluation functions are ideal for this (Fig. 2).

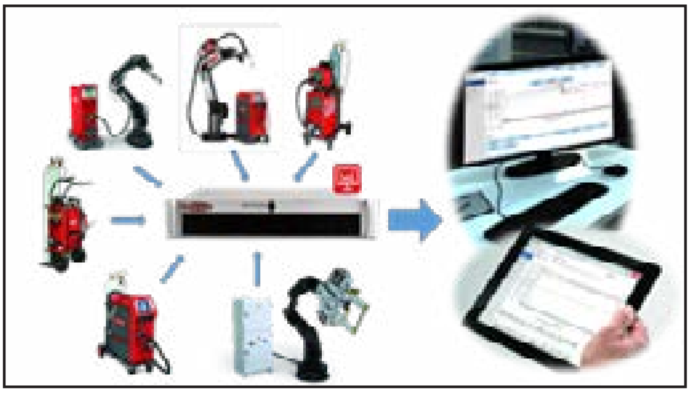

Fig. 2. Fronius WeldCube – intelligent welding data management

2.5. Data security

In fact, the innovative approach behind Industry 4.0 is to provide data across product or system boundaries to deliver better solutions to a wide variety of tasks in a larger context. This analysis can be automated by software systems or by domain experts.

In addition to a high degree of computerization of the individual production facilities, their integration into local networks, open network structures and globally valid standards for data communication, data transfer and interfaces are necessary for the implementation of this approach.

As a result, so-called "cyberattacks" on the local corporate networks could ultimately take place via production facilities. For this reason, the machine manufacturer, but also the user, has to deal intensively with the topic "Cyber security of his production facilities" and install special protection software and devices. Fronius internal studies have shown that the best security levels can be ensured by a combination of electronic hardware authentication and special security software.

Welding torch position identification

It is rarely discussed, but one of the main factors influencing weld quality is the timing of torch positioning relative to the part along the weld path. In the case of automated robot welding systems, the topographic measurement of the part surface and the position of the welding torch can already be reliably performed. In most cases, laser scanners are used and the information obtained is used for the realization of adaptive welding processes. Such processes respond to deviations in the part topology by means of the adaption of torch positioning and power source parameters. In addition deviations of the actual robot movement from the taught default values like, e.g., welding speed, can also be taken into account.

For manual welding tasks the determination of the position of the torch during welding is not yet possible in commercial applications. The lack of an appropriate measurement solution for this task is mainly caused by the high arc exposure, high temperatures, welding fumes, metallic part surfaces and limited accessibility.

Fig. 3. Multilingual, industrial approved touch panels for welding power source operation

Communication human<>welding machine

The fully autonomous welding cell, which is capable of independently solving welding tasks, is certainly a goal that comes within reach thanks to the use of Industry 4.0 concepts. Due to the complexity of the requirements presented above, their implementation in commercial applications will, however, may require a considerable amount of time and effort. Thus, the welding technologist and the welder will remain responsible for the welding quality of complex welding products in the coming decades. This requires that the means of communication between human and welding machine continue to play an essential role. The current trends in the development of interfaces are significantly influenced by those devices that the welder also uses in his private environment. Smartphones and tablets are ubiquitous and can be used as a benchmark for reducing complexity for the operator. Abilities such as multilingualism, touch operation, voice control, etc. are already making their way into the harsh workshop environment (Fig. 3).

Driven by developments in telecommunications such as the Google Glass or the Microsoft HoloLens, the welding helmet is increasingly coming into focus as a communication platform between man and machine. The rather old idea to display welding parameters in the protective glass of the helmet is becoming of more and more interest. In addition, the helmet could also be equipped with voice control, which is connected to the power source. To enable this, it is necessary that the helmet can be wirelessly connected to the power source. Recent developments already make such a connection helmet <> power source possible. Through this connection, the power source sends information about the status of the arc to the helmet. The helmet then utilizes this information to control the automatic darkening function of the protective glass accordingly. This prevents non-response of conventional auto-darkening in light or obscured arcs (Fig. 4).

Fig. 4. Wireless connected helmet to improve self--obscuration of the welder`s helmet protective glass

Virtual welding

Before the autonomous Industry 4.0 welding cell manufactures a real part, it is necessary to create the welding program in off-line mode, to define and check the torch movement in order to avoid unnecessary rejects. This procedure is unavoidable especially if it comes to single piece production. For this purpose, special software systems will be needed in the future, which are able to represent the welding process virtually. The basis for their development will be those software programs that are already being used in the training of welders and robot programmers to virtually train the correct programming of torch holding and movement on the robot (Fig. 5).

Fig. 5. Fronius Virtual Welder – Robotic Virtual Welding

Metal additive manufacturing

The consistent implementation of the Industry 4.0 concept will enable the automated, needs-based component manufacturing of components in the future. 3D design data are sent to the "factory of the future", whereupon the manufacturing process is immediately triggered and the finished product is immediately returned through optimized logistics chains.

In order to reduce production times, which are also significantly influenced by waiting times for materials and set-up times, generative manufacturing processes are becoming increasingly interesting. These "additive manufacturing" technologies produce complex components by targeted melting of special powders or wires.

In the case of generative processes that can produce metallic components, laser, electron beam, and arc processes are used to create a defined part through a precisely-tuned "lay-on-lay" construction of molten metal. Very complex, smaller components can be realized by the laser-powder process [8]. For larger components with lower requirements on the shape complexity wire-based arc welding methods come in the foreground due to economic aspects. Investigations have shown that the CMT ("Cold Metal Transfer") process is an extremely efficient process, especially in these applications. This digitized MIG/MAG process, which ensures an extremely low-energy and almost spatter-free material transition through an additional high-frequency mechanical back and forth movement [7], enables the economic production of larger components with somewhat less geometry complexity, such as impeller blades, but with material properties, which correspond to those of typical weldments [9].

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