INDUSTRY 4.0 IN WELDING

White Paper

Gerhard Posch, Jürgen Bruckner, Helmut Ennsbrunner

Fronius International

2017

If it comes to discussions about the next level of industrialization "Internet of Things" / "Industry 4.0" are frequently used technical terms. The vision they stand for, is clear: The actual ongoing digitalization can provide valuable data but its benefit is restricted and very limited. If this data will be shared to a big community much more experts and scientists could use it and develop new solutions which generates new knowledge and brings a remarkable increase in customer benefits. To enable this, it is necessary to equip almost everything with information and communications technologies of modern PC`s and to connect them to a cyber world, the internet. The overall goal of I4.0 are autonomous working smart factories. All necessary manufacturing information is available in the cloud, intelligent software tools manage and control manufacturing processes and organize the supply chain and goods will be produced on demand by additive manufacturing technologies.

This impacts also welding and the welding equipment development: welding parameters have to be digitalized, microprocessors will take over the essential part of the welding hardware and customized software will play in future the key role. And also big challenges will arise: ultrahigh speed data communication within the welding machine but also within the internet and the development of strategies for securing data and cyber security. Last but not least virtual welding will get a necessary tool to bring the digital information into a manufacturing equipment and to check the plausibility.

INTERNET OF THINGS & INDUSTRY 4.0

What are the trend-setting technical achievements and how will they influence the development of our economy within the next decades? A quite interesting question but almost impossible to answer.

"Internet of Things (IoT)" and "Industry 4.0 (I4.0)" are nowadays one of the most used technical terms if it comes to discussions about trends and visions regarding the next level of industrialization and the "Factory of the Future". Thereby IoT and I4.0 are used as synonyms for the global technical evolution, which could come true within the next decades based on the knowledge mankind has gained till today [1, 2]. By analysing the vision behind it gets obvious, that the revolutionary aspect is the digital networking of all kind of devices, machines and manufacturing systems in real time. In transforming all imaginable information into digital data and sharing this huge set of data on a digital platform, the internet, a very big potential for improvement is seen. By using, analysing and interpreting this "big data" economic benefits up to 70% can be realized by tailor-made software tools in the area of supply chain, manufacturing and predictive maintenance and by implementation of the customer into the value chain [3]. Furthermore new "business ecosystems" between customers, supplier, 3. parties and also competitors in respect to manufacturing, logistics, supply chain, quality management and maintenance could emerge. The transformation of information into digital signals, the so-called "Digitalization" and real-time communication is thereby seen as a main requirement.

The digital connection of physical objects like production tools and manufacturing equipment with the virtual world is actually seen as the most important driver for innovation. Three key areas are identified, which will raise the economic benefit [3]:

/ The use of IoT and 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, realtime "Big Data" analysis and development of prediction models for optimization/quality control systems within the value chain

Actually there is a huge gap between reality and its virtual image as many properties of real components like colour, shape, material or conditions like temperature, environment, degeneration are not transformed into virtuality. The overall goal of IoT is to digitalize and to provide any kind of information about "things" to a huge digital community, named as "internet". Via the internet the digital transformed information, the "data", can be used to create new (digital) knowledge and services by combining the very specialized knowledge of experts with the relevant data by creating tailor-made software tools.

This also implies that in future the development, use and quality of software will play a key role in customer relationships. Any technical hardware advantages of any product, if not related to the digitalization, will be shifted into the background as they can hardly be exploit by the user.

The basis for IoT is the digital transformation of any kind of information and knowledge which strongly triggers the development of specific measuring/analysing hardware like sensors in combination with electronic devices for the digital translation of e. g. manufacturing data, physical condition of the product, topography and motion of any kind of objects during their whole life time. As this will generate a lot of data an innovative digital archive solution is required: based on a worldwide network of storage media which provide almost unlimited capacity, the so-called "cloud" will evolve. That`s why governments and/or telecommunication companies are dared to establish the necessary physical network infrastructure which enables high speed data transmission.

Beside an ethic attitude as IoT data can of course characterize and monitor its user, a few essential aspects have to be considered to bring IoT into life: As each component of an object will deliver data to the cloud a very efficient standardization in sending, transmitting, receiving and processing of data is necessary and all components must have a microcontroller and a common, easy to establish and safe connection to the internet. Additionally the costs for entering the IoT must be low and cheap software tools must be available which take over some of customer´s activities whether automatically or even autonomously.

With the need for standardization another topic gets more and more into focus: data security. The generated data is very sensitive as it could give information about everything which comes into physical, but also virtual contact with object during its life time – manufacturer and customer information, production conditions, quality documents, quantities, involved companies and workmen, but also geographic information. Data, which could also be interesting for 3. parties which try to generate out of this data other than direct business-related consumer information. Dealing with open networks, standardized interfaces, immense data transfer and storage in industrial application requires also new and improved data safety concepts, which is indeed a challenge for conventional-thinking technical equipment manufacturer.

INDUSTRY 4.0 & WELDING

The consequent realisation of I4.0 will also change the “Factory of the Future” towards to the “Smart Factory” [4, 5]. To run a “Smart Factory” more or less regardless of humans a few criteria have to be fulfilled: First of all the necessary welding knowledge of the welding engineer has to be digitalized in a way that a computer can make successful decisions comparable to them of the engineer. Then the welding hardware has to be equipped with microprocessors and various types of sensors for transforming any kind of information into digital data. The necessary requirement for real-time data processing demands a special focus on data communication. The associated storage of big generated data implies open network structures to provide sufficient memory, data security and cyber security.

It´s obvious that the focus of the welding power source supplier has to change: In the initial state of welding the transformation of power was the key to success, nowadays the digitalization of the welding process is the mandatory task and in near future data communication, real-time welding data control, big data storage, cyber security and intelligent human/machine interfaces are the driving forces in hardware development.

But as long as the overall digitalization process in welding is not completed the welder will play the key role and the communication between welder and welding equipment will stay a big issue.

DIGITALIZED WELDING KNOWLEDGE

A welding cell has to be supported with the right welding parameters and if necessary, welding consumables and auxiliaries, depending on the allotted welding task. This requires for autonomous working cells that relevant digitalized knowledge and data is available which is stored somewhere in the cloud. That’s why the welding machine has to be firmly connected to a high speed net so that the microprocessor of the welding machine can receive the mandatory input data for e.g. selecting the adequate synergic line. In case of arc welding it is information about type and dimension of the base metal, welding consumable, shielding gas, joint geometry and welding speed. This basic information is necessary for a proper selection of the welding process and its parameters. Currently it is the welding engineer, who takes over the responsibility to choose the right set-up based on his experience and knowledge. When in future this task has to be taken over by the “cloud” all this human experience and knowledge needs to be digitalized and knowledge management systems, eventually based on neuronal networks, have to be established. This will be maybe the biggest challenge of I4.0 as it is very difficult, to digitalize knowledge. It is hard to quantify and often it cannot be described in exact figures. But an inaccurate digital description is in contradiction to a conventional data base approach. A problem, which was recognized already decades ago in attempts to develop a computer-based material selection system [6]. If it comes to welding it gets much more complicated as this is a highly intersecting topic between material selection, welding procedures, interaction with the heat source, metallurgy and joint properties. The complexity is at a very high level and that’s why the welding knowledge will be probably one of the last items which will be fully digitalized.

MICROPROCESSOR-BASED WELDING POWER SOURCE

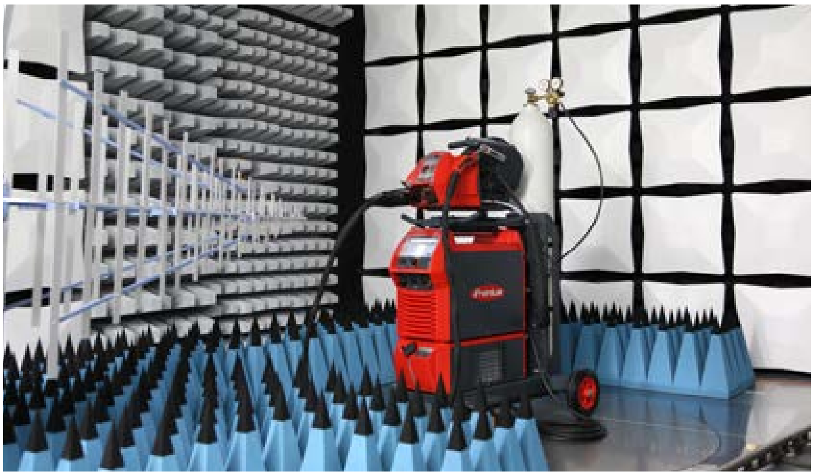
“I4.0 ready” machines are equipped with a microprocessor. Depending on the machine`s job the computer inside has to be more or less powerful. In case of a GMAW welding power source many different tasks thereby have to be executed by the computer:

/ Very fast synergic line processing
/ Welding parameter control algorithms
/ Welding data measurement and at least short-term storage
/ welding power limitation in respect to the “weakest” installed component
/ Providing all possible network functions for cable networks (e.g. Ethernet), wireless networks (e.g. Bluetooth) and nearfield communication (NFC)

/ self-detection and self-testing of installed components like welding torch, wire-feed unit, cooling unit and display

This requires a lot of different electronic components and integrated circuits for fulfilling these demands and implies, that the electromagnetic compatibility of the welding machine, which is at the end a power electronic device, is guaranteed any time. Additionally the electronics have to operate in a very harsh, dirty and dusty industrial surrounding. To guarantee a functional assurance innovative design concepts are necessary, which have to be approved in comprehensive hardware tests, while the welding power source is in operation (picture 1). Tasks, which turned out to be maybe the biggest challenge in the development of power sources since its beginning.

Picture 1:
Test of the electromagnetic compatibility of a welding power source



DATA COMMUNICATION

One of the key words in "I4.0" is "communication" – but how fast is "communication" in welding? In case of GMAW welding this could be estimated by a small calculation: Modern short arc processes, like CMT [10], are working at a droplet detachment frequency up to 150Hz, which means 1 droplet each ~7 ms. To optimize the droplet transfer it is necessary to interact at least 50-100 times during one short arc cycle which ends up in a communication time of around 30 µs from the electric arc to the microprocessor, which includes the measuring and digitalization of the necessary physical data and the transfer of the data to the microprocessor. Maximum the same time can be scheduled for data processing and welding parameter control actions done by the microprocessor. Beside this digital communication requirements also the handling of a huge set of data is challenging. As this data set cannot easily be transferred in real time via the net to an external "master mind" computer for processing, the power source manufacturer has to bring the computer quite close to the arc. That´s why Data Communication has to be divided into two areas: high speed communication within the power source and data communication between the power source and the "cloud".

WELDING PARAMETER SELECTION & DATA STORAGE

The aim of I4.0 is to establish autonomously working manufacturing cells. Therefore a computer has to select, to control and to modify the welding parameters. The control of the parameters needs real-time response and requires as already discussed a powerful computer next to the arc. The selection of the adequate synergic line as a function of base metal, sheet thickness and gap is more or less independent from the actual welding situation an can be done in the cloud by a "welding knowledge management system" but as already mentioned earlier, the development of such management systems will take its time.

On the other hand data storage will get more and more into the interest of the customers – not only for documentation but also for analysing regarding possible inferences with weld failures and wear part management. As at the moment such inferences are not investigated in detail, the minimum resolution of digital signal recording to provide sufficient information cannot be defined and that`s why there`s a strong request towards to high-resolution long time data recording. As the therefore mandatory high-speed connectivity of the welding power source to the "cloud" cannot be guaranteed, the data storage has to be done at special hardware storage tools which are connected and aligned with the power sources (picture 2).

Picture 2:
Fronius WeldCube – intelligent welding data management

DATA SECURITY

The innovative aspect behind I4.0 and IoT is, as already discussed, providing and sharing big data to gain the maximum customer and manufacturer benefits. This requires open nets and worldwide valid standards for communication, interfaces and data transfer. Additional manufacturing machines and also welding power sources will have an integrated powerful computer which runs on a common operating system. But this can make the machine vulnerable against cyberattacks and if the power source is integrated into a local network, it can also make the whole intranet vulnerable. That`s why the power source supplier but also the user must take special precautions to prevent an unauthorized cyber access. As Fronius internal studies have shown, the highest level of cyber security can only be achieved by a specialized hardware key in combination with an intelligent software.

WELDING TORCH POSITION IDENTIFICATION

It is seldom discussed but one of the most quality influencing factors is the position of the welding torch in respect to the workpiece and its angles of attack. As the torch is normally curved it is very difficult to keep these angles constant during robotic welding along 3D trajectories. The information about the real position of the torch in the welding cell in combination with the position of the prepared joint and the clearance, caused by misalignment of the parts is necessary to develop self-correction strategies which can be implemented in special software tools. As the topographical survey of the component, which has to be welded, can be done by using video-, laser-, or ultrasonic-based systems, the torch position is much harder to digitalize as the electric arc interferes due to its radiation, high temperatures, brightness and welding fume emission with the conventional sensors, a "GPS-like" approach is hardly to realize. Due to automation it is possible to describe the position of the torch during welding. The real welding speed, especially in case of short or heavy curved seams, has to be delivered by the automation equipment/robot as delays due to accelerating/decelerating of the guidance equipment are not considered in the presettings.

COMMUNICATION HUMAN/WELDING MACHINE

An autonomously working welding cell is for sure the overall target, but it will take a long time till its realization and humans will stay the responsible operators of the welding machines for the next decades. To facilitate communication the operation of them should be similar to the operation of telecommunication mass products e.g. smartphones: multilingual operation, touch panels (picture 3) and voice control have also to be implemented into welding machines – but under consideration of much harsher environmental conditions, which is a further technical challenge.

Picture 3:
: Multilingual, industrial approved touch panels for welding power source operation

Driven by latest technical progress in telecommunication, like google Glass or Microsoft HoloLens, also the welding helmet gets more and more into focus as a communication platform between humans and welding machine. The vision is to display e.g. welding parameters at the protective glass of the helmet. Additionally the helmet is equipped with a voice control system which interacts with the welding power source. Therefore it is necessary, that the helmet is connected wireless with the welding power source. Newest developments already use connected helmets and improve the self-obscuration of the helmets by sending arc on/ arc off signals wireless to the helmet. This allows a very quick and accurate obscuration especially in case of low-intensity arcs (picture 4).

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

VIRTUAL WELDING

Before the I4.0 autonomous welding cell starts to weld on a real workpiece, it has to be checked, if the offline generated welding process will work and the movement and position of the torch is always in an optimum constellation. Therefore it is essential to run and control the welding task virtually in advance which requires special virtual welding software tools. From this perspective, software tools for training of robot programmers which are already established (picture 5), are a firm base for the development of I4.0 virtual welding software tools.

Picture 5:
Fronius Virtual Welder - Robotic Virtual Welding

6. METAL ADDITIVE MANUFACTURING

A consequent pursuit of the I4.0 concept ends up in a manufacturing of components "on demand". 3D design data will be send to the "smart factory", the manufacturing process will be immediately initiated and the finished product will be soon delivered. In best case the object will be completely generated in intelligent machining cells by additive manufacturing technologies. In case of metal additive manufacturing laser-, electronbeam-, or arc welding processes are the basis and fundamental knowledge about welding is mandatory to develop "fit for service" components. In principle 3D structures will be built up by a precise layer by layer deposition of melted powder- or wire-based filler metals.

As it was already shown [9], GMAW, especially CMT ("Cold Metal Transfer"), as a powerful, very precise and lowest spatter GMAW short-arc process based on a high-frequent reverse wire feeding characteristic [7], enables cost-efficient additive manufacturing of large 3D geometries. The achievable shape complexity is limited compared to common powder-bed processes [8], but mechanical properties of additive manufactured components are similar to already known all-weld metal properties of filler metals, the welding technology is established and not that challenging. Additionally the equipment and prematerial costs are comparably low. Preconditions for a future key role in "manufacturing on demand".

LITERATURE

[1] Ashton K.: „That Internet of Things Thing“; RFID Journal, 07/2009

[2] Wischmann S., et al.: „Industrie 4.0. Volks- und betriebswirtschaftliche Faktoren für den Standort Deutschland. Eine Studie im Rahmen der Begleitforschung zum Technologieprogramm AUTONOMIK für Industrie 4.0.“; Bundesministerium für Wirtschaft und Energie, Berlin, 2015

[3] Bauernhansl T., Krüger J., Reinhart G., Schuh G.: „WGP-Standpunkt Industrie 4.0“; WGP e.V., 2016

[4] A. Roser: „Trumpf baut in Chicago Demofabrik für Industrie 4.0“; Trumpf GmbH; 06/2016

[5] H. Waltl: „Modulare Montage spart Zeit und Kosten“; AUTOMOBIL PRODUKTION 11/2016

[6] Berger W., Posch G.: “ Aspekte der Werkstoffauswahl und Entwicklung eines computergestützten Auswahlsystems / Aspects of material selection and development of a computerbased selection system“; Doctor thesis, TU Graz, 1997

[7] Fronius Int.: “Current Welding Practice: CMT Technology”, DVS Media GmbH, Düsseldorf (2014); ISBN 978-3-945023-36-5

[8] Petrat T., Graf B., Gumenyuk A., Rethmeier M.: „Laser-Pulver-Auftragschweißen zum additiven Aufbau komplexer Formen“; DVS-Berichte 315, DVS Media GmbH, Düsseldorf (2015); ISBN: 3-945023-46-7

[9] Posch G., Chladil K., Chladil H.: „ Material properties of CMT-metal additive manufactured duplex stainless steel Blade-like geometries”; Weld World, DOI 10.1007/s40194-017-0474-5

Fronius International GmbH
Froniusplatz 1
4600 Wels
Austria
Telephone +43 7242 241-0
Fax +43 7242 241-953940
sales@fronius.com
www.fronius.com