Welding Certification for Autonomous Robotized Welding

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***Abstract*— The increased production of more and more complex products challenges the accuracy of manual welding, and increase the time it takes to program automatic welding systems. The main objective for the article is to explore if current regulations and standards are able to accommodate the shift from automatic welding to autonomous welding systems. To do this, the most current and applicable standards have been analyzed. The findings are that most of the current standards have room to accommodate autonomous systems, given that the correct safety precautions are taken.**

***Keywords*— automatic, autonomous, certificate, GTAW, robotic, standards, welding**

I. Introduction

Since the first spot welding robot where installed [1] at general motors in 1962, and later the first dedicated arc welding robot by OTC Japan in 1979 the field has evolved fast. Historically, robotic arc welding was regarded as a complex shift for most production companies. It has been looked upon as a change that required a high volume of repetitive welds to justify the investment. Moreover, that it required a highly skilled operator and programmer to fine tune and monitor the welding process. Robotic welding has long been profitable for lager manufacturers, but has been more challenging for medium sized and job-shop companies to justify. This is about to change, a new report from Market Research Reports suggests an annual growth of 6.09 % during 2014 – 2019 in the global industrial welding robot marked [2]. They also state that one of the main challenges is the awareness of robot welding at a regional level or at the end user. What drives the marked is the increased usage of industrial robots, primary in the automotive industry. Whit the introduction the AWS Certification Program for Robotic Arc Welding - Operators and Technicians [3] (American welding society), it is hoped that the threshold for investing in robotic welding will be lowered. This also paves the way to shift from automatic robot welding to autonomous robot welding. The shift to more autonomous welding processes is a change that will move the responsibility for the weld quality from a person and over to a computer system. This poses challenges in how to control the quality and who is responsible if anything goes wrong. Current standards will be analyzed along with trends in this shift, and usability of these will be questioned. One other question that needs answer: who is responsible if the robot makes a not satisfactory weld? Moreover, if that not satisfactory weld cusses an accident. A resent tragic incident from Germany, where a robot accidentally killed a worker by pressing him up against a metal plate and crushing his chest [4] must act as a warning to the force available in industrial robots. In addition, it must remind us that one of the key factors in automation of manual labor is the safety for the workers.

II. Limitations

This paper only discuss the certificates regarding three different types of electric arc welding, also referred as Shielded Metal Arc Welding / SMAW, Gas Metal Arc Welding / GMAW or Gas Tungsten Arc Welding / GTAW. Some of the findings may be transferable to other welding types, but that is not taken into consideration.

III. Current Certificates

A. *Manual, mechanical and automated welding*

Manual welding, this is the basic form of welding. The operator holds the torch. This allows the welder to be close to the weld, and is able to control the speed, heat and feed rate. Mechanized welding, the welding torch is mounted on a trolley or other device. Thus, removing the welding operator from direct contact whit the weld. This process is still under the direct control of the operator, so he / she must supervise and adjust the speed of the torch, alternatively the oscillation, heat and feed rate. This is similar to manual welding. However, the operator is removed from direct contact whit the weld. This allows for the usage of higher speed and greater heat. Due to the less strenuous conditions for the operator, this also allows for longer welds. Booth in time and distance. Automatic welding, when an operator programs an automatic trolley, or a robot, to follow a path and a given set of parameters. Whit inn these parameters the apparatus is allowed to adjust its own settings. The tolerance for error in the pieces that are assembled are relatively low, and the torch can be snagged on the imperfections.

B. *Welding certificates*

According to gowelding.org [5] welders are certified in structural / plate and pipe welding. Inside those categories, there exist a coding system to identify what kind of position /

orientation the welder is qualified to perform. For structural welding the numbers 1 to 4 and the letters F and G is used: 1 stands for the flat position, 2 stands for the horizontal position, 3 stands for the vertical position 4 stands for the overhead position, F stands for a filler weld joint and G stands for a groove weld joint. This means that a 4F is a vertical weld done using a filler joint. When it comes to structural certifications in particular, groove welds will also qualify the welder for fillet welds. However, fillet welds do not qualify the welder for groove welds. Most codes allow a welder to take a combination of the 3 and 4G positions, which typically qualifies the welder for all position structural welding plus pipe that is a minimum of 24 inches in diameter. Inn pipe welding the numbers 1, 2, 5, 6 and letters R, F and G is used. 1 is for a pipe in the horizontal position that is rolled, 2 is for a pipe in the fixed vertical position, 5 is for a pipe in the fixed horizontal position, 6 is for a pipe in a 45 degree fixed position. R is for the restricted position, F is for a fillet weld and G is for a grove weld. Here a combination of 2 and 5G is used to prove that the welder is qualified to weld in all pipe positions. The R limits the clearing around the weld spot, and forces the welder to work within a narrow space; it also forces the welder to use both hands. In addition, ISO – 9606 – Qualification testing of welders — Fusion welding [6], certifies welders to work whit different materials. It consists of five parts. Part 1: Steels, part 2: Aluminum and aluminum alloys, part 3: Copper and copper alloys, part 4: Nickel and nickel alloys and part 5: Titanium and titanium alloys, zirconium and zirconium alloys. There exists other standards. Some apply in one country or region, such as Germany or the EU. However, the most used, and universal accepted is the ISO and ASME (American society of mechanical engineers) standards. According to TWI (the welding institute) [7] the certificates obtained under AWS (American welder society) and ISO criteria are usable in most countries. In addition, there exist special standard regarding welding on high-pressure components, or equipment for use in nuclear reactors. These certificates are the same for manual, mechanized or automatic welding. As mentioned, the AWS has developed a certificate that apply for robot arc welding. For now this is only a certificate that is available in northern America. The curriculum and tests are being revised to better harmonize whit the ISO standards. The purpose is to ensure that the beholder is qualified to operate a robot. The main reason for this is the higher complexity of a new welding robot compare to a new automatic welding machine. This ensures that the operator understands the welding process and the complexity of the kinematics of a robot. Modern flexible welding systems for job-shop setup can be made up of a seven-axes robot, equipped whit a two-axes welding table.

C. Current Situation for Autonomous Robotized Welding

AWS has developed a certification program specified aimed at robotic arc welding, this is as mentioned called CRAW. They future categorized three levels of users: level 1 and 2 operator and technician. The specifications are lied out in AWS QC19:2002, second print April 2009 [8]. The basis of knowledge to obtain this certificate is made up by several different AWS standards and other sources:

- AWS A3.0 Standard Welding Terms and Definitions
- AWS B1.10 Guide for Non-destructive Inspection of Welds
- AWS B1.11 Guide for Visual Welding Inspection
- AWS B5.1 Qualification Standard for AWS Welding Inspectors
- AWS QC1 Standard for AWS Certification of Welding Inspectors
- AWS WI, Welding Inspection
- AWS CM-00 Certification Manual for Welding Inspectors
- AWS B2.1 Specification for Welding Procedure and Performance Qualification
- AWS D8.8 Specification for Automotive and Light Truck Weld Quality: Arc Welding
- AWS D16.2 Standard for Components of Robotic and Automatic Welding
- AWS D16.3 Risk Assessment Guide for Robotic Arc Welding
- AWS D16.4 Specification for the Qualification of Robotic Arc Welding Personnel
- ANSI Z49.1 Safety in Welding, Cutting and Allied Processes
- NEMA EW-1 Electric Arc Welding Power Sources
- AWS Arc Welding with Robots, Do's and Don'ts
- Automating the Welding Process, Jim Berge, Industrial Press
- AWS Welding Handbook, Volume 1, 9th Edition
- AWS Welding Handbook Volume 2, 8th Edition
- Robot Programming Manual (published by robot manufacturer)
- AWS 058 Arc Welding Automation, Howard Cary
- AWS A2.4 Standard Symbols for Welding Brazing, and Non-destructive Examination
- Jefferson's Welding Encyclopedia 8th Edition
- RIA 15.06 American National Standard of Industrial Robots and Robot Systems – Safety Systems

These standards only take into consideration the technical side of autonomous robotized welding, it is assumed that anybody who apply for this certificate is familiar to ANSI Z49.1, Safety in Welding and Cutting, and Allied Processes and RIA 15.06, American National Standard of Industrial Robots and Robot Systems - Safety Systems.

IV. CRAW AS BASIS FOR AUTONOMOUS WELDING

A. Personnel

AWS D16.4 Specification for the Qualification of Robotic Arc Welding Personnel [9] describes the qualifications required for the three different levels of CRAW certificates, level 1 and level 2 operator and technician. When discussing certified robotic welding there needs to be a department head that is ultimately responsible for the weld quality of that plant or department. In that regards it is wise to use the qualifications of a CRAW –T (Certified Robotic Arc Welding Technician) as a guideline. AWS D16.4 outlines the following (p.4):

1) *Skills and Ability Requirements*

- Have the ability to make changes to the weld data, torch angles, electrode stick out, starting techniques, and other welding variables. Have an extensive welding background and a thorough understanding of the robotic interfacing system.
- Demonstrate a thorough understanding of all aspects of the robotic work cell. Demonstrate programming, robotic arc welding, seam tracking, fixturing, and any other welding or robotic related functions. Have the capability to enter the work cell and make changes to the weld program, main program, torch clean program, or any other related programs. Capable of fixture changes to improve part fit up and part locating.
- Be capable of performing file management tasks, such as saving, copying, and deleting program files.
- Demonstrate expertise in the welding operations including all of the arc welding robots, automated welding equipment, and all manual welding operations.
- Be responsible for the initial weld inspection and be familiar with the tools that measure the weldment quality.
- Have the ability to perform weld cross sectioning by cutting, polishing, and etching appropriate samples when necessary.
- Keep accurate and up to date records, including issuing revised weld procedures as needed.

2) *Experience and Education Requirements*

- Meet all of the experience and education requirements from previous levels.
- Have a minimum of 3000 hours or 3 years arc welding experience.
- Have a two year Associates Degree in Welding/Robotics/Electrical or equivalent combination of appropriate education and experience.
- Hold current CWI certification (Certified Welding Inspector).

3) *Training Recommendations*

- Obtain training in the proper operation of cross sectioning tools and related hardware such as plasma cutting and band saws.
- Obtain instruction in the applicable destructive testing methods used, such as macro etch or bend testing.
- Receive instruction in the operation of quality measuring tools, including applicable computer software for measuring weld cross sections.
- Complete programming courses offered by original equipment manufacturers or equivalent robotic programming courses.
- Become familiar with personal computers and relevant software.

B. Terms and definitions

AWS A3.0 Standard Welding Terms and Definitions [10], AWS A2.4 Standard Symbols for Welding Brazing, and Non-destructive Examination [11]. These standards ensures that everybody that is welding and / or programing welding machinery are talking the same language. This is to minimize errors and misunderstanding due to miscommunication. It is important that this form the basis for all machine human communication. They also outline the symbols that should be used in the design process. Using the same symbols means that humans and / or machine will use correct welding methods.

C. Inspection

AWS B1.10 Guide for Non-destructive Inspection of Welds [12] and AWS B1.11 Guide for Visual Welding Inspection [13]. B1.10 outlines several methods for inspecting a weld without causing any structural damage. The methods covered in the standard is visual, liquid penetrant, magnetic particle, radiographic, ultrasonic, electromagnetic (Eddy Current), leak. In addition, the methods for visual inspection are described in B 1.11. It states that currently x-ray is the fastest method for inspecting welds, but it has a problem detecting deformations going parallel whit the weld plane. Ultrasonic inspection is regarded at the best method, and using a multi beam ultrasonic device will most likely detect all deformations in any direction. The information in these standards needs to be in cooperated in an automated system for non-destructive testing of welds. Wenfei Chen, Zuohua Miao and Delie Ming [14] has created an x-ray based inspection tool that is able to inspect welding line of steel tubes at "production line speeds". Whit the implantation of high speed processing of machine vision and new algorithms they successfully detected the same fault as a manual inspection. In addition, the system had the capacity to inspect every weld, and not only a selection. Due to the unhealthy outcome from human exposure to x-rays, it is also a good alternative to use ultrasound. Gordon Dobie, Walter Galbraith, Charles MacLeod, Rahul Summan, Gareth Pierce and Anthony Gachagan [15] have produced good results whit ultrasonic technology. They were not able to reproduce the speeds that x-ray are able to, that is mostly due to the usage of Wi-Fi to upload the images. The maximum detection speed in this device was 20 mm/s. Moreover, this product is developed for an autonomous unit for inspection inside pipes. Mounting this devise on a robot, whit a cabled data connection would solve this problem. Both these solutions are interesting in the scope of certified robotic welding.

AWS B5.1:2013 [16], AWS QC1 [17], AWS WI [18] and AWS CM:00 [19] outlines the qualifications and demands on a welding inspector. It is this authors belief the even the most advanced systems are still designed by humans, and thus being a victim of human error. One system cannot be allowed to control itself. This means that highly skilled human inspectors must do some sort of random control of the welds. Furthermore, the information must me in cooperated in the quality system for the inspection of welds.

D. Parameters

AWS B2.1 Specification for Welding Procedure and Performance Qualification [20] outlines the parameters for welding carbon steel to austenitic stainless steel in the thickness range of 0.82 mm2 through 5.26 mm2 filler wire using gas tungsten arc welding (TIG). It cites the base metals and operating conditions necessary to make the weldment, the filler metal specifications, and the allowable joint designs for fillet welds and groove welds. AWS D8.8M Specification for Automotive and Light Truck Weld Quality: Arc Welding [21] further outline the requirements for making an approved weld for the automotive industry.

Inn all arc welding there is a need for a power sours, the specifications for these is found in NEMA EW-1 Electric Arc Welding Power Sources [22]. Depending on the material, the thickness and depth of the weld, the settings on the power supply have a great impact on the result. In DC welding, we differ between negative and positive electrode. When using a positive electrode we usually get a deeper penetration than a negative electrode. However, a positive electrode has a higher melt of, and therefore a higher depositing rate. In AC welding, we get the benefits for both these types of welding. In a more advanced setup, it is possible to manipulate the ratio of polarity, frequency and even the form of the curve (sine / square). Giving the welder the possibility to manipulate the width of the arc and the penetration. We also can differ between the current in the negative and positive phase. For instance, frequency and waveform manipulation can be used for cleaning / removing the oxide coating when welding aluminum.

Jefferson's Welding Encyclopedia 8th Edition [23], this book contains information on different materials. The information includes data on melting point, heat transfusion and heat distortion. This information can be combined whit data gathered from automatic metal classification. In combination whit automated measuring, this would allow a robotic weld system to calculate the maximum transferee rate of filler material. Eranga Ukwatta and Jagath Samarabandu [24] have achieved a 99 per cent identification rate using Laser-induced Breakdown Spectroscopy and a high definition video camera. This method utilizes an artificial neural network and a set of metal samples to "train" the system to recognize different metals. The system is cheaper and easier to run on computer systems than the exiting spectral analyses. In addition, it is less susceptible to pollutions and impurities.

In an autonomous welding system the software have to device a welding procedure specification (WPS) or weld recipe by itself. The document contains detailed information, included but not limited to, the materials, position of welding, filler material, shield gas, flow rate, number of passes, welding current, pre-heat temperature. Kranendonk has developed a software called RinasWeld [25] for just this purpose. By importing a CAD-drawing into the software, it can identify the weld path, create a WPS and use this information in an offline program for a robot. The software can utilize multiple robots at the same time, generating a 100 % collision free robot path.

To ensure that the WPS produces good welds, a Procedure Qualification Record (PQR) have to be produced. This is a proof test of the weld recipe (WPS) is able to make a weld that has the strength required. This is a proof that the WPS is valid and ready to be used in production.

Normally a Welder Performance Qualification Record (WPQ) also have to be produced. This document states that the welder is capable to follow the WPS and produce good welds. This will not apply for an autonomous welding system. This is based on the fact that robots will copy every movement exactly like they did on the first run.

E. Components

AWS D16.2 Standard for Components of Robotic and Automatic Welding [26] defines what is needed in order for a system to qualify as a robotic arc welding installation. Robotic arc welding systems consist of a manipulator, power source, arc welding torch and accessories, electrode feed system, de-reeling system, shielding gas delivery system, welding circuit, shielding and communication control, and grounding system. Note that the standard does not require a safety system. However, RIA 15.06 American National Standard of Industrial Robots and Robot Systems – Safety Systems [27] and AWS D16.3 Risk Assessment Guide for Robotic Arc Welding [28] gives a good introduction into what systems needs to be in place to qualify for a safe workplace. RIA 15.06 also form the basis for ISO 10218 Robots and robotic devices - Safety requirements for industrial robots.

F. Safety

ANSI Z49.1 Safety in Welding, Cutting and Allied Processes [29], RIA 15.06 and AWS D16.3 have good guidelines for what must be in place and what should be in place. The RIA 15.06 is considered a game changer for the robotic industry, it introduces some new concepts. In addition, a welding cell must be covered by a screen, or similar contraption, to shield people from the UV-light produced by the welding process.

1) Functional safety

The goal of implementing functional safety is to define, as well as quantify, engineering solutions (safety measures, techniques and procedures) that need to be implemented to achieve an acceptable safety hazard level in compliance with the safety standard. In other words: Supplied components and their integration into the safety-related control system must meet the required safety performance level and have the life expectancy needed to meet the system's overall functional safety.

2) Safety-related Soft Limits (SRSL)

Historically, robotic safety and safeguarding was all about hardware-controlled limits to a robot's movements, combined with access restrictions to the potential motion space. When ordering a "new" robot with the proper Safety Rated Soft Limit and/or manufacturer hard stop options the system can be programmed to use a smaller portion of the robot's maximum reach area. By doing so the restricted space can be reduced to closer match the shape of the required work envelope. Thus, less perimeter safeguarding can be used and the guarding will enclose less floor space. Now that SRSL's are safety-rated and accepted by national standards. This can be of great benefit since it allows further optimization of floor space. The overall floor space required by the robotic system is reduced by integrating the proper safeguard devices into your safety control system.

V. Conclusion

The process of going from automated to autonomous welding may be both a technical and political challenge. It is the authors opinion that one of the best way to start is to begin in parts of the industry where welding is considered to be especially hazardous. Meaning welding inside tanks and "hard to reach" places. The software and hardware solutions have evolved to the point that it is capable of taking decisions that will result in a high quality weld. One more important aspect is to keep humans in the loop in a supervision capability. Moreover, given the proven track record of robots in the industry and the safety guard in place. There is a good chance that we will see the first certified autonomous robotic welding systems in near future.

Acknowledgment

The authors wish to thank the support and financing to the Research Council of Norway (BIA 245691, CoRoWeld).

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