IOP Conf. Series: Materials Science and Engineering **274** (2017) 012041 doi:10.1088/1757-899X/274/1/012041

Research on the Effect of Welding Speed on the Quality of Welding Seam Based on the Local Dry Underwater Welding

Lei Liu *, Wu Chen, Huagang Wang, Jinyu Ba, Bing Li

China Nuclear Power Technology Research Institute, Shenzhen 518124, China

*Corresponding author e-mail: liulei2@cgnpc.com.cn

Abstract. The repair of nuclear spent fuel pool has a high requirement for the quality of welding, the welding speed directly affects the quality of the weld when local dry automatic underwater welding is used to repair the damaged surface. Under the condition of the same condition, the local dry automatic underwater welding test was carried out under the condition of the same welding condition. Taking the 20cm as the experimental condition, after massive experiments show that when the welding speed is approximately 48cm/min the weld quality is high, meeting the design requirements, based on the double layer shrinkage nozzle chamber of local dry underwater automatic welding.

1. Introduction

As a clean and efficient energy, nuclear power has always been a key construction project in developed countries since the United States EBR-1 in 1951, the French nuclear power capacity even accounted for 80% of the national power generation, with less oil imports to achieve the export of electricity. However, the operation of nuclear power plants is much more complicated than that of thermal power, which not only has high technical complexity, but also has serious accidents such as nuclear leakage caused by man-made or natural disasters [1].The United States stopped the construction of nuclear power plant since 1979 because of the serious accident at the San-li Island nuclear power plant in Pennsylvania, the former Soviet Union Chernobyl nuclear accident in Ukraine is still endangering the local ecological environment. Nuclear spent fuel pool is the pool of nuclear waste storage, in order to prevent chain reaction, nuclear spent fuel pool is generally equipped with a certain concentration of boron water [2]. At present, the nuclear spent fuel pool of the Daya Bay nuclear power plant is already saturated and the nuclear spent fuel pool faces a lot of welding repair work. Due to the particularity of the nuclear spent fuel pool [3], the development of dedicated underwater automatic welding robot can not only avoid nuclear radiation to harm the human body, but also to overcome the limitations of human physiology, to complete the welding work. The current underwater welding methods are wet welding, dry welding and local dry welding, where the local dry underwater welding is the welding area of the water discharge, for the welding area to create a similar to the dry welding environment [4].

A special local dry underwater welding robot system was developed for the emergency rescue and repair of nuclear power plants. The system has dedicated underwater DSC full digital welding power supply, compact diving wire feeder and local dry underwater Drainage hood, integrated fault diagnosis system and other ancillary equipment. As the welding speed directly affects the welding rate and then

affect the quality of welding, so the welding speed of the process is very important. According to the existing welding process, set a relatively moderate speed range, in ensuring the reliability of the test under the premise of effectively reducing the test process [5].

2. Welding power supply development

This paper uses the method of melting gas metal arc welding (GMAW), a 600A all-digital inverter structure underwater dedicated welding power supply is equipped with the experiment. The core of the welding power supply is ARM Cortex-M4 microprocessor, which has a dedicated floating-point unit (FPU) and digital signal processing (DSP) instructions with data processing capability of 210DIMPS, 1MB ROM memory Capacity, and a large number of I / O devices for signal acquisition, processing, control and output, in addition to the communication function, fully meet the underwater welding power development. The overall diagram of the development of the welding power supply shown in Figure 1.

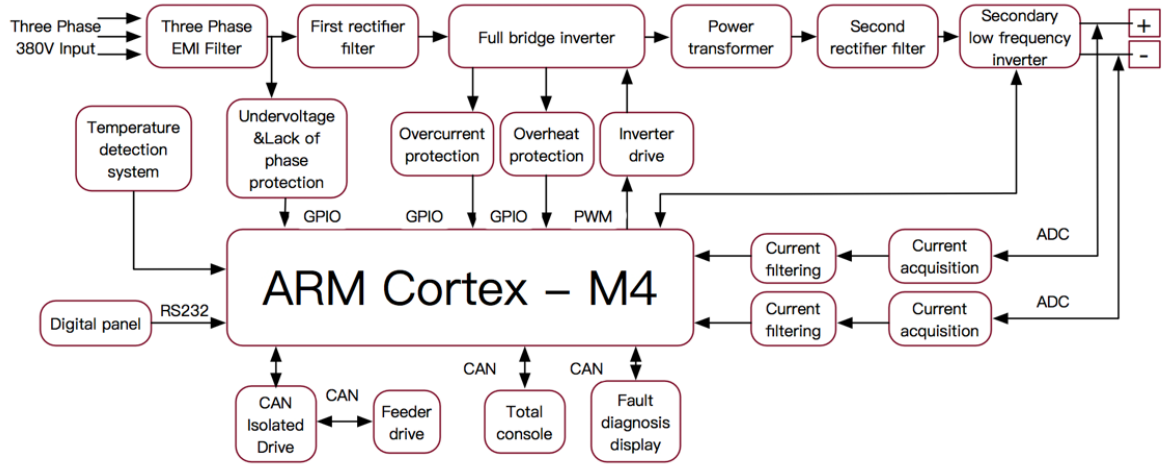

Figure 1. Overall frame of the welding supply

The main circuit of the welding power supply includes EMI filtering, three-phase rectifier circuit, full bridge inverter, intermediate frequency transformer, secondary rectification and secondary inverter structure. EMI filter use safety capacitor, high permeability core and power resistance, which can effectively inhibit the interference signal in the power grid to improve the quality of the output waveform. The pulse width modulation signal (PWM) is output by the timer counter of the DSC microprocessor [6] and the signal is processed after driving the IGBT. The CAN bus and fault self-diagnosis alarm communication processing procedures was also developed to make it possible for remote monitoring of the welding power supply in real-time, which effectively avoid the contact between radiation environment and human. The physical map and the main control board of power supply for local dry underwater welding are as shown below.

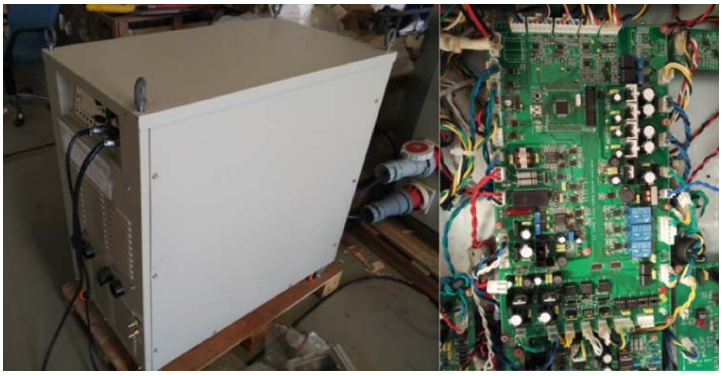

Figure 2. Power supply for local dry underwater welding and main control board

3. Submersible wire feeding device

A dedicated diving wire feeder is developed to protect the smoothness of underwater welding process. The speed of this wire feeder must be adjustable and can be welded in the depth of 20m, the error should not exceed 10% at the same time. The shell of wire feeder is corrosion-resistant aluminum alloy material, the front panel is transparent PVC (polyvinyl chloride). In order to enhance the reliability of the wire feeder, inside the wire feeder into the gas to reduce the pressure between inside and outside, and real-time adjustment of the internal pressure is operated according to the depth of the work, so that the pressure inside and outside to maintain balance [7].

Speed regulation of the diving wire feeder is voltage regulation, user can monitor the wire feed speed through the motor voltage. The selected motor is a special wire feeding mechanism of Nanjing SSR-5A, which is simple in structure, reliable in operation, small in size and small in loss. It is very suitable for layout in a small enclosed space. The parameters are shown in Table 1 below.

Table 1. Motor Parameters

Power	Rated Voltage	Rated Current	Weight	Wire Feed Speed	Wire Diameter	Wheel Size (Out x In x Thickness)
80W	24V	5A	3Kg	2.0-16 m/min	φ0.8-φ1.6 mm	φ35xφ25x8 mm

For better waterproof sealing, the barrel of the wire feed machine has a groove with a thickness and a width of 3 mm around the front edge. It is used to place a rubber gasket with a circular cross section, the transparent panel is tightened with M8 bolts. The motor is changed from vertical to parallel, further reducing the overall size of the wire feeder. The physical map of the submersible wire feeder is shown in Figure 3 below.

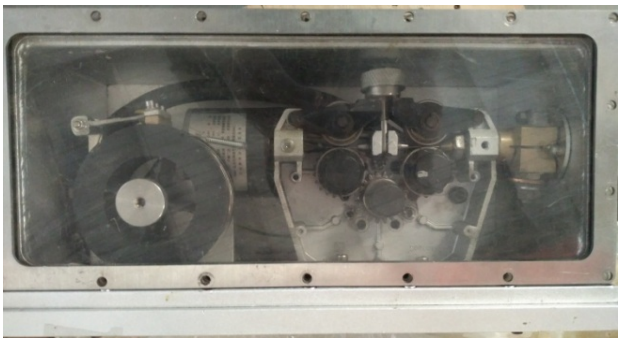

Figure 3. The diving wire feeder

4. Experiment and analysis

As the test method of underwater local dry welding, the design of welding process is very important. Underwater local dry method is a special way to drain the water in the welding area, which create environment similar to the dry welding. Underwater local dry method of drainage has curtain, steel brush and mobile containers [8], which water curtain and steel brush type drainage diagram are shown in Figure 4 below.

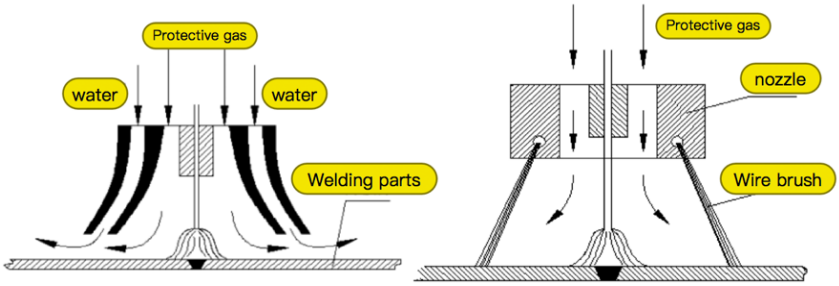

Figure 4. The schematic structure of the curtain chamber and the steel brush chamber

The high-pressure water curtain of the outer curtain of the curtain-type drape mainly stabilizes the combustion of the inner gas in the air chamber formed by the protective gas, but the stiffness of the high-pressure water curtain is not high enough, the depth of welding is shallow because the isolation effect is not ideal. The steel brush-type drainage hood is an improvement of the water curtain in the drainage hood, which is equivalent to a water curtain instead of a curtain of a water curtain, simplifying the equipment while also allowing the drain cover to withstand deeper water pressure. The mobile chamber drainage cover is a movable air chamber with a sponge mounted below, wrapped in the weld area, but there is a requirement for the flatness of the surface of the weldment, so the degree of automation of the moving chamber drain is not high [9].

As the drainage hood connected with the welding gun, its design directly influences the quality of underwater welding. The advantages and disadvantages of drainage design are mainly determined by the way of drainage, external structure, manufacturing materials and design cost. In the design of local dry water underwater drainage hood, innovation in drainage mode has been the focus of research. Based on the advantages and disadvantages of the above-mentioned underwater local dry welding, this paper has developed a set of drainage cover for underwater local dry welding. The drainage method and 3D schematic of the drainage cover are shown in Figure 5.

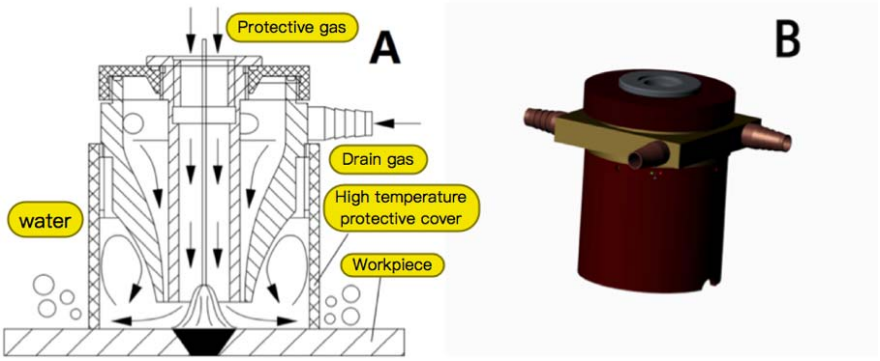

Figure 5. The internal flow and the 3D structure diagram of chamber

In the case of underwater local dry welding, the optimum pressure value of the protective gas and the drainage gas in the drainage hood shall be determined. When the pressure value is measured, the

welding speed is set to 42cm / min according to the actual experience of land welding. As shown in Table 2 below.

Table 2. Experimental conditions of local dry welding

Name of parameters	Parameter value
Welding method	DC pulse
Peak current I_P(A)	320
Base current I_B(A)	60
Pulse frequency f(Hz)	100
Peak current duty cycle d_p(%)	32
Welding speed v(cm/min)	42
Protective gas pressure p_i(MPa)	Test requirements
Drain gas pressure p_o(MPa)	Test requirements
With / without drains	With

The gas that passed into the drain is divided into two, the arc protection gas from the upper part and the four drainage gases from the side of the drain, the pressure of the arc protection gas is measured by a large number of process tests: Welding speed, the welding depth is set to 20cm, 0.2MPa is a more appropriate pressure value. The direction of the four drainage gases entering the interior of the drain is tangent to the sides, forming a rotating air curtain after the confluence of the drainage hood. The area of the outer cavity of the drain cover is gradually reduced, with the expansion of the gas, when the drainage gas flows out of the drainage hood, the gas is accelerated and close to the outside of the cavity. The stability of the rotating air curtain formed by the drainage gas is high and the continuity is better. Combining the obstruction of the external high temperature protection sleeve to the water pressure can form a stable gas phase inside and ensure the stable combustion of the arc.

In the case of protective gas 0.2MPa, the other experimental conditions are the same, after a lot of experiments, measured 0.15MPa drainage gas under the formation of the weld effect is better. Figure 6 below shows the formation of the weld under the condition of water depth of 20cm, the protection of gas pressure 0.2MPa, drainage pressure of 0.15MPa.

Figure 6. The welding seam with speed of 42cm/min

Whether onshore or underwater welding, the effect of welding speed on weld quality is the most direct. From the weld in Figure 6 can be observed, although other parameters can achieve a reasonable effect, but the shape of the weld is still more serious black and hump phenomenon, poor quality molding, the main purpose of this study is to use the test method determines a reasonable welding speed.

Underwater welding environment is different from that on the land, prone to arc or heavy arcing difficult, broken arc, droplet transfer uniformity and other issues are prone to appear, due to the particularity of the underwater environment, even the existing underwater welding process is difficult to ensure that the quality of welding is not affected by the environment. Therefore, how to weld

underwater reasonably become the focus of the study[10]. In the research of underwater local dry welding, Zhang Tong from South China University of Technology experimenting the local dry underwater welding in the micro-drainage hood in 1995, which shows that the mechanical properties of dry welding are stronger than that of wet welding through the microscopic analysis of the microstructure, also the diffusion of hydrogen in the welding process is lower. Zhu Jia-lei from Beijing University of Chemical Industry has developed a local dry automatic underwater welding system in 2009, the system can simulate the 15m depth of the local dry welding environment. 2011 Nanchang University Chen Hai-jun developed a new drainage hood, which use a shrink nozzle to accelerate the airflow so that the water around the weldment will be separated from, thus to achieve local dry welding, the test results good [11].

Based on the special method of underwater local dry welding, this study uses the comparative test method to determine the impact of welding speed on arc combustion and weld forming. The test conditions are in accordance with Table 2 except for the welding speed, the speed is set to 36cm / min, 48cm / min and 60cm / min, also set the median current to 0A, the later median time duty cycle is 0%.

The actual installation of the air intake of drain cover and welding site are as shown in Figure 7 below, underwater welding is operating in the laboratory's dedicated water tank, the entire welding process is controlled by welding power supply.

Figure 7. The welding seam with speed of 42cm/min

The weld effects at weld speeds of 36 cm / min, 48 cm / min and 60 cm / min are shown in (a), (b) and (c) of Fig. 8, respectively.

(a) The welding seam with speed of 36cm/min

(b) The welding seam with speed of 48cm/min

(c) The welding seam with speed of 60cm/min

Figure 8. The welding seam at different welding speeds

Figure 8 (a) of the welding speed is the slowest in welding process, the droplets can be in a larger range of transition, so the pool is also wide, forming the weld and the base metal contact range is larger. When the speed is accelerated, due to the energy concentration during the welding process is not enough, will inevitably produce: droplet transfer efficiency is reduced, the width of the weld is reduced, as shown in Figure 8 (b) below. When the welding speed significantly exceeds the appropriate welding speed, the droplet transition range is further reduced, and due to the quenching of water, the weld will be accompanied by significant black edge phenomenon. Too fast will lead to the production of hump, also the weld uniformity is poor, weld and plate fusion effect is poor, as shown in 8 (c) below.

5. Summary

The welding speed is directly related to the forming effect of the weld. When the welding speed is low, the range of the droplet is larger, the weld is wider, but the welding quality is not significant, and the lower welding speed will lead to longer repair time. When the welding speed is high, the droplet transition range is small, the weld is narrow, the contact area between the weld and the base metal is small, the welding quality is difficult to meet the requirement. A large number of tests show that in the depth of 20cm underwater, the weld quality is better to meet the design requirements at the speed of 48cm / min.

Acknowledgments

This work was financially supported by National Energy Application Technology Research and Engineering Demonstration Project fund (NY20140202).

References

[1] Li HL, Liu D, Yan YT, Guo N, Feng JC.Microstructural characteristics and mechanical properties of underwater wet flux-cored wire welded 316L stainless steel joints[J].Journal of Materials Processing Technology.2016,238:423-430.
[2] Wu Hongbo, Wang Zhidong, Xiang Bing. Domestic and international nuclear power development situation analysis [J]. Energy Technology Economy .2012 (03): 5-9.
[3] Wang Hai-tao, Shan Jian-qiang, Gou Jun-li, Zhang Bo. Study on accident of LOCA condition in spent fuel pool [J]. Nuclear Power Engineering .2015 (04): 136-139.
[4] Feng Yunliang. Nuclear spent fuel pool underwater local dry robot welding power supply [D]: South China University of Technology.
[5] Wang Zhenmin, Feng Yunliang. Underwater robot local dry welding system [J]. Welding Journal .2017,38 (1): 5-8.
[6] Wu Kaiyuan, Huang Shisheng, Li Yang, Lu Peitao. Digital control technology of arc welding power supply [J]. Semiconductor Technology .2005 (01): 72-75.
[7] Gao Hongyu. Underwater welding wire feeder development and underwater welding technology experimental study [D]: Harbin Institute of Technology.
[8] Zhu Jialei. Nuclear power plant maintenance of local dry automatic underwater welding technology research [D]: Beijing University of Chemical Technology.
[9] Duan Yu, Chen Xiao-qiang, Tang Yao. Application of New Underwater Local Dry Welding [J]. Metalworking (Hot Working) .2013 (12): 46-48.

[10] Qi Li, Zhang Jun, Huang Guan-xing. Flow field analysis and structural parameter optimization of steam ejector based on Fluent and Workbench [J]. Fluid Machinery .2014 (05): 35-38.
[11] Zhang Tong, Zhong Ji-guang, Wang Guo-rong.Study on Local Dry Method Underwater Welding of Flux Cored Wire Micro-Drain Cover [A]. China Society of Mechanical Engineering Welding Society [B]. The 9th National Conference on Welding Conference (Volume 2) [C]. 1999: 358-361.