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DESIGN AND MANUFACTURE A CONTROLLER OF ORBITAL TIG WELDING EQUIPMENT

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Abstract – *Currently, the welding industry faces significant challenges when human resources with highly specialized skills are increasingly scarce, especially in pipe welding. Because this process requires care, meticulousness, and high precision to produce stable, good-quality welds, automatic welding devices in various welding methods were created to solve this problem. In particular, the Tungsten Inert Gas welding method is widely applied in industries that use stainless steel pipes. Hence, the manufacture of automatic welding equipment based on this method is essential. Therefore, this research focuses on researching controllers that can be combined with ordinary Tungsten Inert Gas welding powers available in the Vietnamese market and automatic welding heads that have been researched and developed in recent years. In this solution, the operator will set welding parameters such as welding current, welding speed, arc pulse time, welding start position, and rotation direction on the touch screen. In this control unit, welding parameters are controlled by a central processing unit in combination with stepper motors, relays, and rheostats. Therefore, the contribution of this research will open opportunities for the research and development of Orbital Welding systems in developing countries.*

Keywords: automatic welding parameters, orbital TIG welding, welding controller.

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I. INTRODUCTION

Stainless steel pipes are commonly used in various industries and applications due to their durability, corrosion resistance, and high strength. Therefore, stainless steel pipes are a versatile and reliable choice for multiple applications across various industries due to their numerous beneficial properties. In particular, the Tungsten Inert Gas (TIG) welding technique is known for its practical applications in welding stainless steel pipes. This method uses Tungsten electrode to melt the metal and form a weld after crystallization. Orbital TIG welding (OTW), a unique variation of this technique, plays a vital role in automating welding processes, significantly improving weld performance and quality [1]. The principle of this welding method is that a Tungsten electrode will be moved 360 degree by the mechanical actuator (gear or belt) around a fixed pipe to create a weld (Figure 1). However, continuous efforts to develop and perfect the technique have created high-quality welds with low defect rates and optimized weld seam surfaces. Orbital welding technology produces more consistent and precise welds compared to manual methods, thereby reducing inconsistencies in sensitive pipe and tubing welds [2].

In recent studies [3–6], the parameters of OTW, such as welding speed, weld current, pulse frequency, and shielding gas composition, have been investigated and shown to show the efficiency of optimizing welding parameters to ensure high-quality welds. Orbital welding is a testament to the continuous efforts of global engineers and contributions from many countries, such as Europe, North America, and China, in developing this industry [3]. Manufacturers have continuously improved and integrated features to

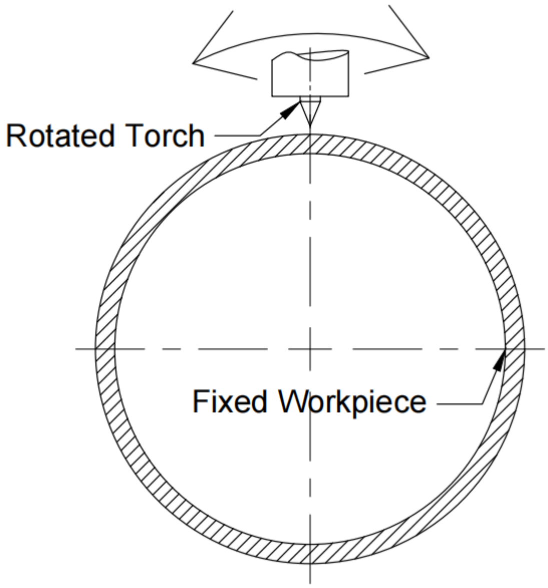


Fig. 1: Principle of TIG orbital welding

bring convenience to operators. First, there is the Orbitalum Smart Welder OM180, which has an advanced control system that allows input and retrieval of information related to the operation process and can be shared through the connectivity option in line with the trend of industrial communication networks (IoT / Industry 4.0). Besides, this device can use input voltage from 110 V to 230 V with a frequency of 50/60 Hz or 1-phase power without needing a dedicated industrial power supply [4]. In addition, orbital welding machines are provided by KEPUNI, which can block dangerous radiation rays from reaching the human body by limiting welders to direct contact with welding equipment. In addition, the system supports operators in simplifying usage through welding parameters that are automatically generated from the expert's database system. This makes it possible for beginners to weld high-quality welding seams quickly [5]. Finally, the TITANIUM 230 AC/DC FV manufacturer offers a welding solution that combines single-phase and DC AC power, providing optimal productivity for welding aluminum, steel, stainless steel, and copper materials and their alloys. Not only that, this equipment also has a variety of assembly types: butt weld, lap weld, interior and exterior corner [6].

The devices mentioned above reflect the development of orbital welding technology and significantly improve welding productivity and quality while minimizing possible errors during welding. The controller plays a key role in ensuring the mentioned technical requirements, with the ability to automatically adjust the welding current strength, welding speed, and arc pulse time. This requires a precise and reliable weld head controller capable of performing high-precision tasks and being easily adjustable to suit a variety of materials and welding conditions. This controller must be able to flexibly adjust welding parameters and provide a user-friendly interface while integrating advanced technologies to optimize the welding process. This helps to minimize errors and enhance production efficiency. In addition, the controller needs to automatically detect and adjust parameters during welding, ensuring each weld is up to high-quality standards. With the support of advanced welding head controllers, enterprises can optimize the profitability of orbital welding technology, create high-quality products, and expand their competitiveness in the market. This step forward in the welding industry promotes economic and technological development in Vietnam. At the same time, this research also contributes to the construction and development of the domestic welding industry.

II. METHOD, DESIGN AND EXPERIMENT

A. Design requirements

The OTW controller is an efficient and innovative pipe welding solution suitable for the actual situation in Vietnam. This equipment is designed to be compatible with the most popular welding machines on the market, and automatic pipe welding heads have been researched in the country. Therefore, the controller must also ensure functional and technical requirements.

Functional requirements:

1. The controller must correctly adjust the current, voltage, speed, and welding position.

2. The Human Machine Interface (HMI) display is clear and intuitive, ensuring easy operation for the operator.

3. The system works stably, ensuring the welds have high synchronization and esthetics.

4. It is possible to input and monitor parameters during welding easily.

Technical requirements:

1. The control program is upgradeable, ensuring compatibility with future technological advances.

2. The protective cover design for the controller should ensure robustness, dust resistance, and impact resistance.

3. It is necessary to design the system to ensure electrical safety and protect the health of operators in compliance with safety standards.

B. Automatic welding system structure

The welding device includes controllers, TIG welding power, and OTW heads (Figure 2).

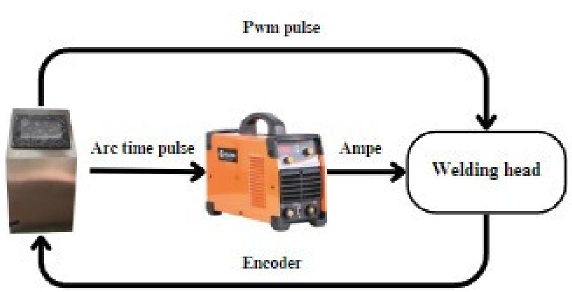


Fig. 2: The Orbital TIG welding

The controller combines Mitsubishi Fx3u-14MT PLC, driver, and signal reader from the return sensor. This Programmable Logic Controller (PLC) has 14 digital outputs, allowing users to connect and control various devices during automation flexibly. Along with high compatibility, this board supports many communication ports, such as RS485, RS232, and the like, making it easy to integrate into modern industrial network systems. Users can easily program and maintain control programs through a convenient programming environment. The driver has a high resolution of 6,400 pulses/revolution and meets stable and smooth control of the welding trajectory. At the same time, it can minimize heat generation when operating the step motor. The sensor reader supports many industry-standard output signals with high accuracy, convenient for device communication.

This equipment is designed to be compatible with the most popular welding machines. The welding head device must be designed with a compact, flexible size that allows change and adjustment to fit a variety of pipes of different diameters. This welding head is also equipped with an advanced insulation system, ensuring maximum safety for the user during the welding process and preventing all risks of electric shock.

C. Control system

Based on actual requirements, the control system is designed to gain the needs of efficient operation and management. Figure 3 illustrates a block diagram describing how an automated pipe welding system works.

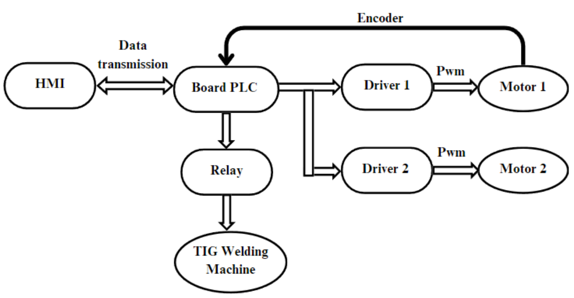


Fig. 3: Control system of Orbital TIG welding

This block diagram provides an overview of how components interact with each other to make up an efficient and accurate OTW system. This is an essential first step in developing and implementing OTW systems in industrial production.

The control system includes four main components.

1. The Mitsubishi FX3U-14MT is responsible for managing the entire system.

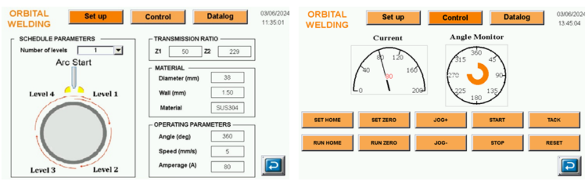
2. The step motor helps to operate the mechanical actuator.

3. The HMI creates an interface between the operator and the device.

4. The amperage controller.

The HMI console consists of three tabs: Set-up, Control, and Datalog.

Set-up tab: This tab sets the welding parameters such as diameter, thickness, arc angle, and welding speed (Figure 4a).

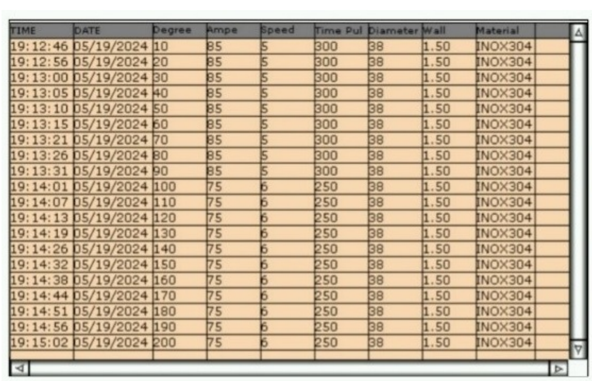


a) Set up tab of HMI b) Control tab of HMI

Fig. 4: HMI display of the controller

Control tab: Used to operate the welding process, set the Home and Zero positions, and handle operation (Jog+/Jog-) (Figure 4b).

Datalog tab: This tab records all parameters during the welding process (Figure 5).



TIME	DATE	Degree	Ampe	Speed	Time Pul	Diameter	Wall	Material
19:12:46	05/19/2024	10	85	5	300	38	1.50	INOX304
19:12:56	05/19/2024	20	85	5	300	38	1.50	INOX304
19:13:00	05/19/2024	30	85	5	300	38	1.50	INOX304
19:13:05	05/19/2024	40	85	5	300	38	1.50	INOX304
19:13:10	05/19/2024	50	85	5	300	38	1.50	INOX304
19:13:15	05/19/2024	60	85	5	300	38	1.50	INOX304
19:13:21	05/19/2024	70	85	5	300	38	1.50	INOX304
19:13:26	05/19/2024	80	85	5	300	38	1.50	INOX304
19:13:31	05/19/2024	90	85	5	300	38	1.50	INOX304
19:14:01	05/19/2024	100	75	6	250	38	1.50	INOX304
19:14:07	05/19/2024	110	75	6	250	38	1.50	INOX304
19:14:13	05/19/2024	120	75	6	250	38	1.50	INOX304
19:14:19	05/19/2024	130	75	6	250	38	1.50	INOX304
19:14:26	05/19/2024	140	75	6	250	38	1.50	INOX304
19:14:32	05/19/2024	150	75	6	250	38	1.50	INOX304
19:14:38	05/19/2024	160	75	6	250	38	1.50	INOX304
19:14:44	05/19/2024	170	75	6	250	38	1.50	INOX304
19:14:51	05/19/2024	180	75	6	250	38	1.50	INOX304
19:14:56	05/19/2024	190	75	6	250	38	1.50	INOX304
19:15:02	05/19/2024	200	75	6	250	38	1.50	INOX304

Fig. 5: Datalog tab of HMI

D. Motion control algorithm

The motion control algorithm is created to operate the OTW head (Figure 6). To fix the OTW head into the pipe, the starting position is determined as the 'Home' position and the 'Zero' position is to start at any point on the pipe, depending on the purpose of the operator. The operator can enter welding parameters into the controller's memory slots to begin the welding process. This solution allows the operator to have a flexible starting position of the arc. Usually, there are four angle positions: 12 h, 3 h, 6 h, or 9 h, with each angle allowing different welding currents, welding speeds, and arc pulse times to be entered.

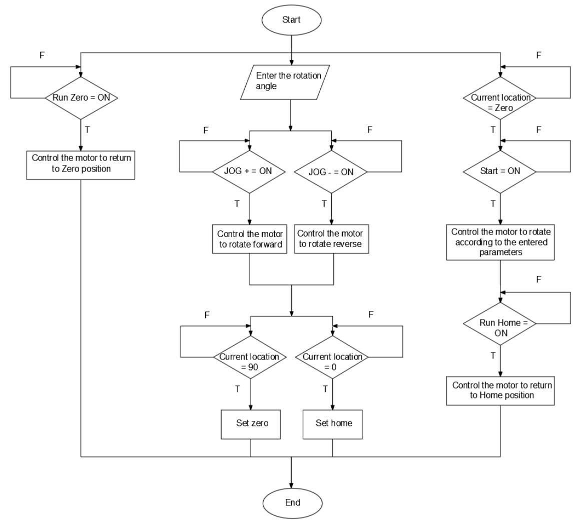


Fig. 6: Control system flowchart

E. Emperimental process

In this experiment, two stainless steel 304 with a pipe diameter of 38 mm and a thickness of 1.5 mm were used to perform the process to evaluate the operability and accuracy of the controller. The pipes are carefully prepared, cut into pieces about 100 mm in length, and tacked to create a butt joint for two pieces of pipe before being welded by OTW equipment (Figure 7). The distance between the two positions is 1,800, and the concentration is not over 15% of the thickness.

Many welds with parameter changes were performed to assess the working capabilities of OTW controllers with the initial requirements. In particular, four welds are set with changes in weld current strength, welding speed, and arc time selected to compare the influence of welding

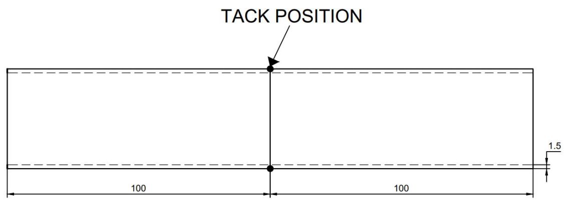


Fig. 7: Welding tack position

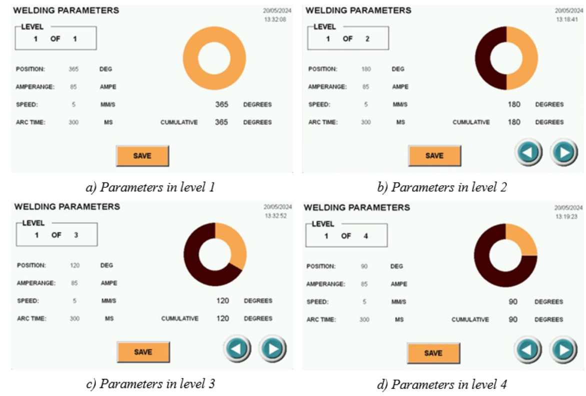


Fig. 8: Set welding parameters for levels in a weld

parameters on weld seam appearance. The welding parameters are set explicitly in Table 1. Other parameters related to this welding process include welding electrodes for WT20 stainless steel with a diameter of 2.4 mm, air flow of 12 LPM, and arc length of 1.75 mm.

Table 1: Table of welding parameters

Code	Position	Amperage (A)	Speed (mm/s)	Arc time (ms)
1	12 h	85	5	300
2	12 h	85	5	300
	6 h	85	6	400
3	12 h	85	5	300
	4 h	76	5	300
	8 h	85	5	300
4	12 h	85	5	300
	3 h	76	5	300
	6 h	85	6	400
	9 h	76	6	400

TIME	DATE	Degree	Ampe	Speed	Time Pul	Diameter	Wall	Material
19:12:46	05/19/2024	10	85	5	300	38	1.50	INOX304
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19:13:15	05/19/2024	60	85	5	300	38	1.50	INOX304
19:13:21	05/19/2024	70	85	5	300	38	1.50	INOX304
19:13:26	05/19/2024	80	85	5	300	38	1.50	INOX304
19:13:31	05/19/2024	90	85	5	300	38	1.50	INOX304
19:14:01	05/19/2024	100	75	6	250	38	1.50	INOX304
19:14:07	05/19/2024	110	75	6	250	38	1.50	INOX304
19:14:13	05/19/2024	120	75	6	250	38	1.50	INOX304
19:14:19	05/19/2024	130	75	6	250	38	1.50	INOX304
19:14:26	05/19/2024	140	75	6	250	38	1.50	INOX304
19:14:32	05/19/2024	150	75	6	250	38	1.50	INOX304
19:14:38	05/19/2024	160	75	6	250	38	1.50	INOX304
19:14:44	05/19/2024	170	75	6	250	38	1.50	INOX304
19:14:51	05/19/2024	180	75	6	250	38	1.50	INOX304
19:14:56	05/19/2024	190	75	6	250	38	1.50	INOX304
19:15:02	05/19/2024	200	75	6	250	38	1.50	INOX304

Fig. 9: Table of welding data

Settings and data

Firstly, the OTW head and the controller are connected by signal cables, and the welding head is installed on a fixed pipeline using their clamps. After that, welding parameters are set on the Set-up tab and the Control tab of the controller on a touch screen. Finally, a tacking is performed to check the signal arc before welding. Figure 8 is the interface of the Set-up tab to enter welding parameters for four welds prepared in Table 1.

This automatic pipe welding head controller helps record welding parameters continuously by time and angle to save and monitor during the welding process to help find problems when welds fail. The recording is shown in Figure 9.

III. RESULTS AND DISCUSSION

To assess the precision operation of welding electrodes, the degree of segmentation plays a crucial role in accurately starting and finishing the welding position. The results depicted in Figure 10 indicate that the four tacking points at the 12 h, 3 h, 6 h, and 9 h positions are relatively precise. The center of the tacking points are aligned with the centerlines of the pipe. This suggests that the controller has accurately executed the degree segmentation for the positions set on the control unit.

The welding current is a welding parameter that significantly affects the quality of the weld, so accurately adjusting this parameter plays a decisive role in this study. The results in Table 2

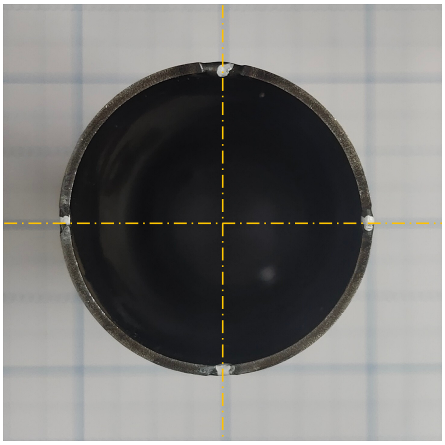

Fig. 10: Accuracy of degree

show that the error is 0 when there is no change in the welding current throughout the welding process (sample 1), but when changing the arc time, an error of 1.2% appears even though the amperage does not alter (sample 2). Furthermore, when there is a change in amperage values from 85 A down to 76 A, the error is 1.3%, and when it increases back to 85 A, the error is 1.2%. This error may come from the error of the step motor that adjusts the welding current, but this error can be accepted as it almost does not affect the appearance of the weld because there is no significant difference between the positions of samples 2, 3, and 4 (Figure 11).

Table 2: The error of amperage adjustment

Code	Position	Amperage (A)		
		Value setting	Real value	Error
1	12 h	85	85	0.0%
2	12 h	85	85	0.0%
	6 h	85	86	1.2%
3	12 h	85	85	0.0%
	4 h	76	77	1.3%
	8 h	85	84	1.2%
4	12 h	85	85	0.0%
	3 h	76	77	1.3%
	6 h	85	86	1.2%
	9 h	76	75	1.3%

Another welding parameter that significantly influences the productivity of orbital welding technology is the welding speed, which is controlled by a step motor and a gear transmission

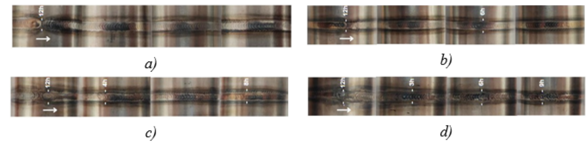

Fig. 11: Visual quality of four welds

to generate the movement speed of the welding electrode in this study. Therefore, the accuracy and stability of the electrode movement were also considered in this study, and the error results of these four welds are recorded in Table 3. The results show that errors occur randomly at each weld line but do not significantly affect the generation of input heat to the weld when the most significant error is 3% [7], so it does not significantly impact the quality of the weld and productivity. In addition, the appearance of sample 1 (Figure 11a) shows that the weld weaves are evenly spaced, and when changing the arc time values in Welds 2 and 4, the stability of the weld scales is also shown. This demonstrates that the controller has achieved stability in controlling the arc time values during the pipe welding.

Table 3: The error of speed adjustment

Code	Position	Speed (mm/s)	Calculated time (s)	Real value (s)	Error
1	12 h	5	23.86	23.90	0.17%
2	12 h	5	11.93	11.59	2.85%
	6 h	6	9.94	10.36	3.22%
3	12 h	5	7.95	8.09	1.76%
	4 h	5	7.95	7.91	0.50%
	8 h	5	7.95	7.88	0.88%
4	12 h	5	5.96	6.11	2.52%
	3 h	5	5.96	5.87	1.51%
	6 h	6	4.97	5.08	2.21%
	9 h	6	4.97	4.89	1.61%

IV. CONCLUSION

Automatic pipe welding technology plays a crucial role in several industries worldwide, including Vietnam. Therefore, the success of this research created a new solution for designing and manufacturing automatic pipe welding control equipment at a low cost, which can connect researched and manufactured OTW heads with available welding sources on the market in Vietnam. This controller can flexibly adjust welding parameters through HMI and achieves the following remarkable results.

1. It can operate the gear transmission carrying TIG welding electrodes, which is decisive in forming automatic orbital welding joints with high precision and stability.

2. It could flexibly adjust welding parameters when experimenting with a pipe diameter of 38 mm and a thickness of 1.5 mm with an amperage error of 1.3% when increasing and decreasing within the range from 76 A to 85 A. In addition, when setting the welding speed from 5-6 mm/s and arc time from 300–400 ms, the most significant error is approximately 3% throughout the 360o rotation around the fixed pipe.

3. The controller is designed with an intuitive user interface and the ability to establish a stable connection between the controller, welding power, and OTW head.

Additionally, the stability and durability of the automatic pipe welding head controller should be assessed. Furthermore, making the controller more flexible and intelligent based on welding temperature will be a future research and development trend for thiVolums technology.

REFERENCES

[1] Back WJ, Lee JW, Lee JY, Lee DH. Development of the Orbital TIG welding robot control system [오비탈 TIG 용접로봇 제어 시스템 개발]. *Korean Society for Precision Engineers*. 2013;2013.05a: 417–418.

[2] Arc Machines, Inc. *Orbital welding vs. manual welding: Comparing advantages and disadvantages*. https://resources.arcmachines.com/orbital-welding-vs-manual-welding-comparing-advantages-and-disadvantages-ami/ [Accessed 27^{th} February 2025].

[3] Lothongkum G, Chaumbai P, Bhandhubanyong P. TIG pulse welding of 304L austenitic stainless steel in flat, vertical and overhead positions. *Journal of Materials Processing Technology*. 1999;89–90: 410–414. https://doi.org/10.1016/s0924-0136(99)00046-1.

[4] Orbitalum. *Orbitalum Smart Welder OM180*. https://orbitalum.us/ [Accessed 27^{th} February 2025].

[5] Kepuni. *XD-20W orbital welding machine*. https://www.kepuniwelder.com/ [Accessed 27^{th} February 2025].

[6] Gys. *Gys Titanium 230 AC/DC HF FV*. https://www.gys-welding.com/ [Accessed 27^{th} February 2025].

[7] Polysoude. *The orbital welding handbook*. www.polysoude.com/wp-content/uploads/2022/01/DOC_Orbital-welding-Handbook_EN.pdf [Accessed 27^{th} February 2025].

[8] Mitsubishi Electric Corporation. *FX3xx programming manual, basic & applied instruction edition*. Mitsubishi Electric; 2021.

[9] Omkar Joshi, Dr. Arunkumar. Overview of orbital welding technology. *International Journal of Innovative Science, Engineering & Technology (IJISET)*. 2015;2(12); 958-959.

[10] Orbital Technik. *Enclose orbital weld heads*. https://orbitechnik.com/welding/#welding2 [Accessed 27^{th} February 2025].

[11] Figueirôa DW, Pigozzo IO, Silva RHGE, De Abreu Santos TF, Filho SLU. Influence of welding position and parameters in orbital tig welding applied to low-carbon steel pipes. *Welding International*. 2017;31(8): 583–590. https://doi.org/10.1080/09507116.2016.1218615.

[12] e Silva RHG, Schwedersky MB, da Rosa ÁF. Evaluation of toptig technology applied to robotic orbital welding of 304L pipes. *International Journal of Pressure Vessels and Piping*. 2020;188: 104229. https://doi.org/10.1016/j.ijpvp.2020.104229.