QUALIFICATION OF A ROBOTIC PIPELINE ORBITAL WELDING

Ivanilza Felizardo, ivanilza@rotech.com.br
Flaviano Lopes Pereira, flaviano@rotech.com.br
Hernandes Coutinho Fagundes, hernandes@rotech.com.br
Rotech Tecnologia Robótica Ltda, Avendia Henfil, 535, Serrano, 30120-070, Belo Horizonte, Minas Gerais, Brasil

Alexandre Queiroz Bracarense, bracarense@ufmg.com.br
Laboratório de Soldagem Robótica e Simulação, Departamento de Engenharia Mecânica, Universidade Federal de Minas Gerais
Av. Antônio Carlos, 6627, Pampulha, 31270-90, Belo Horizonte, Minas Gerais, Brasil

Abstract. *This work presents the procedure qualification for pipeline orbital welding using a robotic system. The system has four degrees of freedom, which allow the controlling of the stick out, the travel speed, the torch angle and the positioning. The arc voltage and welding current are also controlled during the welding, although the system uses a conventional power source. With the system it is possible to use the GMAW and FCAW processes. It was designed for pipes with 305 mm (12 inches) in diameter or more. The robot is not appropriate for root pass yet, since the groove is prepared without control. The biggest problem found in the root pass was the poor repeatability, because of the bisel preparation. The procedure qualification of the system has been prepared. The project standards used for the qualification were B31.4 for oil pipeline in industrial instalation following the welding standards ASME IX – 2003 Ad. 2005 and in field following the welding standards API 1104 – 1999 and B31.3 for refinery and pipeline in industrial instalation following the welding standards ASME IX – 2003 Ad. 2005. The mechanical tests accomplished were tension, bending, hardness, macrograph and nick break. The pipe welded had 500 mm (20 inches) in diameter with 15 mm of thickness wall. The quality was above the expected and even above the manual. The results assured the good use of the robot.*

Keywords*: robotic system, orbital welding, procedure qualification, FCAW, pipeline*

1. INTRODUCTION

In these next 3 years, the construction of more than 6,000 km of pipeline is expected in Brazil. For pipeline welding, among all the welding processes possible to be used, the most common ones are the SMAW (Shielded Metal Arc Welding), the GTAW (Gas Tungsten Arc Welding), the GMAW (Gas Metal Arc Welding) and the FCAW (Flux Cored Arc Welding) (API 1104, 1999). The method of aplication can be manual, mechanical or automatic. Normally, the root pass is made with GTAW, and the filling and finishing passes with SMAW. Recently the application started to change to GMAW for the root and FCAW for the others, due to the need of increase in productivity. One thing that has however held the increase in productivity is the use of welders with these processes, which still does not assure good quality.

There is a great group of parameters (current, voltage, stick out, torch angle and travel speed) for each welding position (plane, vertical up and down and over head). It is very difficult to realize the variation control of these parameters during manual pipeline welding or even with the mechanical method of application and with robotic welding it is very easy.

This work presents the robotic system for pipeline orbital welding. The system controls the variation of parameters during the welding producing welds of excellent quality.

2. ROBOTIC SYSTEM FOR PIPELINE ORBITAL WELDING

The robotic system developed (Figure 1) is composed of three parts: the controller, the manipulator and the power machine. The controller is responsible for all the welding tasks. Both, the manipulator and the power machine, are controlled by it (Bracarense *et al*, 2004; Lima *et al*, 2005, Felizardo *et al*, 2005).

The manipulator was idealized to be compact, light, mobile and easy to attach and hold on to the pipes. Its first version, Figure 2a, showed many problems and the biggest was exactly the attachment. It required an operator interference to adjust the mechanical system idealized and during the operation many times the robot lost orientation. Therefore it was necessary to change to automatic attachment, Figure 2b. The system became more stable with a CC motor keeping the other tasks feasible.

A problem observed in the second version was related to the torch movements. The original motors (step motors), responsible for the angular movement of the torch, were replaced by CC motors. Additionally the size of the torch was studied again and redesigned so that the manipulator was further optimized. Figure 3 shows the actual version.

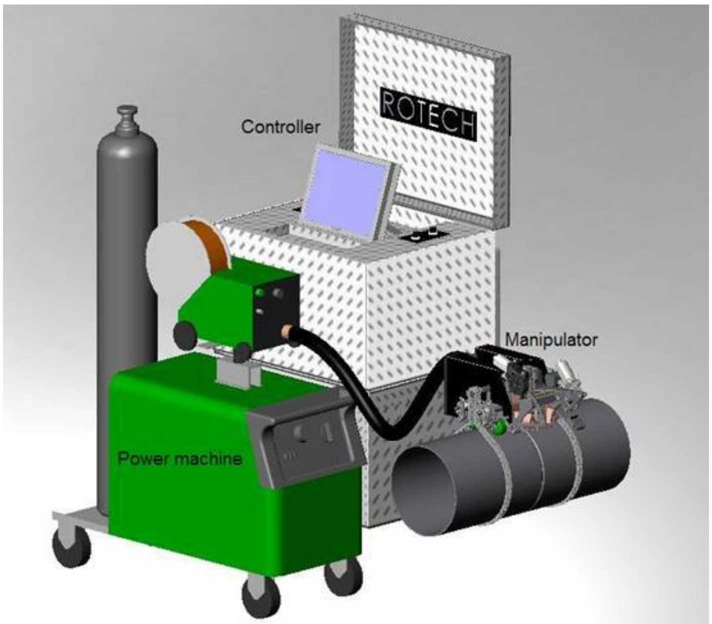


Figure 1. Robotic system for pipeline orbital welding.

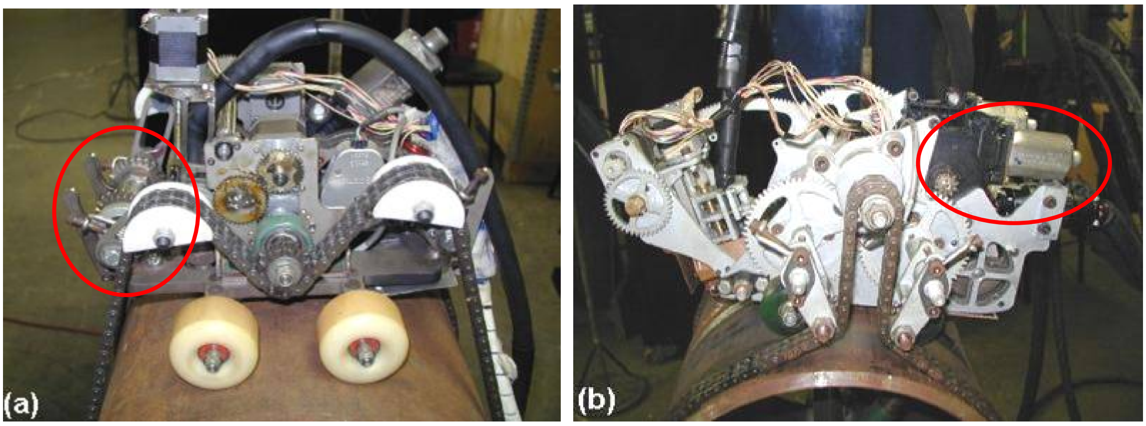


Figure 2. First and second versions of the manipulator. Detail for the attachment system (a) manual and (b) with motor

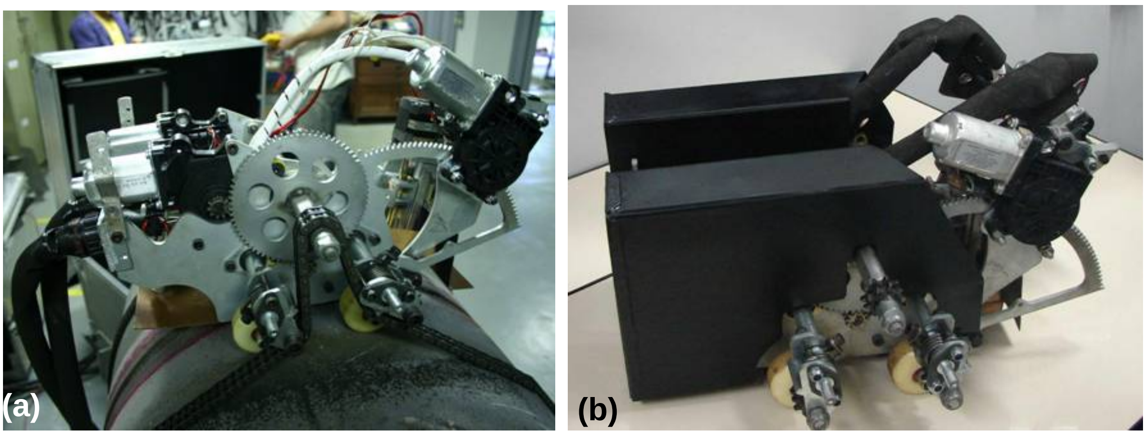
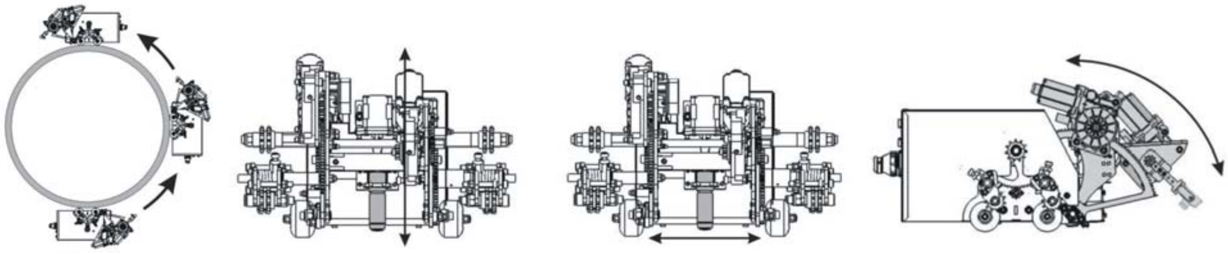


Figure 3. Actual version of the manipulator. (a) Without protection cover and (b) With protection cover

All the versions have four degrees of freedom as shown in figure 4: movement around the pipe (a), stick-out (b), torch lateral (c) and torch angle motion. It is presented each one of these movements, as well as the mechanical solutions adopted to the implementation of them.



a) Translation b) Vertical c) Lateral d) Angular

Figure 4. Degrees of freedom.

In order to provide the translational movement around the pipe (Figure 4a), an electromechanical structure composed by a pair of chains and set of reduction gears was idealized. The actuator sets in motion a set of gears that tracts the chains. The chains involve the pipe in order to keep the robot held under any conditions and making possible the movement of the robot by means of attrition. The set of gears amplifies the motor torque, guaranteeing the controllability of the robotic system.

Stick-out is other one of the welding parameters to be controlled by the system (Figure 4b). In the robot, this movement is carried through by an engine that drives a spindle, and puts into linear motion the welding torch, coming close to and moving away from the pipe, in order to decrease and to increase the size of the electric arc.

The lateral position control of the torch (Figure 4c) is necessary so as to guarantee the perfect alignment between the electric arc and the groove, mainly in the root pass where a small non-alignment can cause lack of fusion in one of the sides of it. The non-alignment is measured through a seam tracker especially designed for the application.

One of the main parameters to be controlled in the robot is the welding torch angle in relation to the tangent in the welding point of the pipe (Figure 4d). This angle determines how the wire will be fed in the welding pool, and its control is fundamental so as to successfully obtain welding in the overhead and ascendant vertical positions. A structure was then designed which is driven by a step motor so as to control the torch angle. This subsystem is composed by a set of reduction gears that provides the profit of ideal torque to the exact position controllability.

In order to drive the movement around the pipe and to control its speed, an DC motor was selected, driven by PWM (Pulse Width Modulation). For the stick-out, inclination and lateral motion degrees of freedom it have been selected step motors which although its reduced dimensions, provide high torque. Moreover, for these movements, position control must be precise, what makes the step motors the perfect choice.

The robot controller is implemented in a PC in which digital output and input boards were added in order to make possible to drive and control the robot axles, as well as the welding machine.

During the program execution, the controller generates reference values to the speed of the first axle and position of the three following axles. The values of welding speed, the torch angle and stick-out are informed through the look-up table of parameters. Thus, for each position of the robot around the pipe (which is read from the inclinometer sensor), it is possible to generate the references with the optimal values for such parameters (Figure 5).

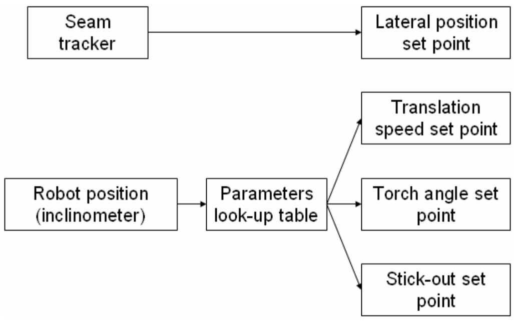


Figure 5. Actuators set points generation

Knowing the reference values, the controller implements the speed control of the movement around the pipe (Figure 6). The speed sampling is performed by means of an encoder located in the axle of the driving motor. Using the encoder pulses frequency, the real speed of the robot is determined with precision. When some error between the reference and the real speed exists, the driving voltage of the driving motor is modified so that the error heads to zero. After calculating the new driving voltage, an analogical signal is generated through a D/A board and sent to the PWM which amplifies the signal power and drives the DC motor.

On the other hand, in the positioning control of the step engines are used drivers that feed the coils in the right order, so as to put them into motion according to the signal sent by the PC.

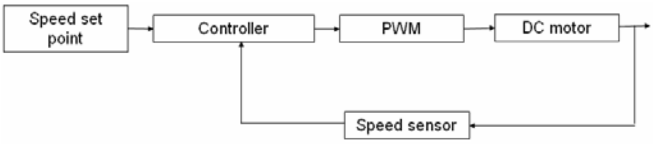
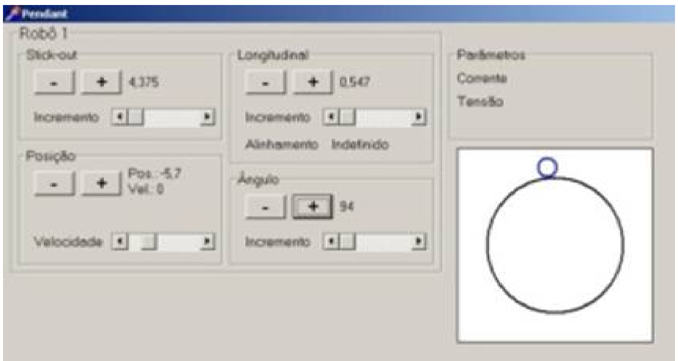


Figure 6. Closed loop speed control

The welding machine used was modified in order to have two independent wire feeders allowing simultaneous use of two robots. Originally, the weld font has a potentiometer for regulation of the welding voltage. Each one of the feeders has a potentiometer for regulation of the welding current (wire feeding speed). Both potentiometers were manual. So, the operator would have to regulate voltage and current before starting the welding. To the robotic process, however, it is needed that the welding parameters (current and voltage) be regulated by the robot itself. Thus, an electronic board was developed to work as the interface between the robot controller and the welding machine.

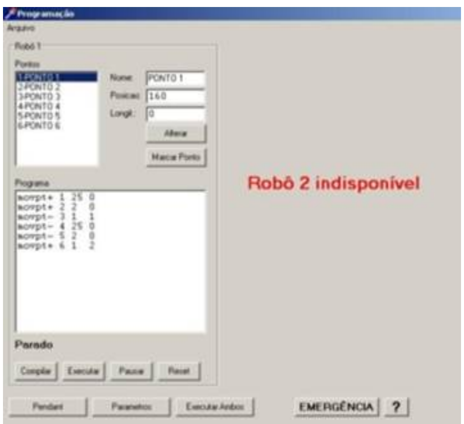
The designed board is capable to vary the electric resistance between 3 terminals substituting then a tripot resistor. The desired resistance is informed by the controller through an 8-bit digital signal allowing a resolution of 256 steps between the minimum resistance and the maximum resistance. The substitution of the electrical resistor which regulates the voltage of the welding font allows, therefore, the regulation of 256 different voltage levels. The same is made to each one of the wire feeders substituting the manual resistors of current regulation by the electronic board circuit. The values of current and voltage to be used are determined by means of the parameters look-up table, in accordance to the robot position around the pipe. The digital values for regulation of the welding font are determined by means of a calibration curve from the welding font

A control board was specially developed to do the interface between the controller and the conventional power source. With this board, the system was considered robotic (Rivin, 1988). In other words, all tasks related to welding are automatic and controlled: torch positioning (vertical, lateral and angular), travel speed, current and voltage change without interference of the welder during the process. Figure 7 shows some screens of the robotic system.

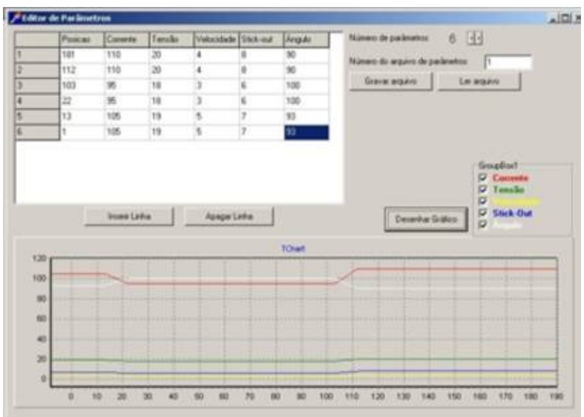


a) pendant

b) off set up



c) program



d) parameters

Figure 7. Example of screens developed for the robotic system

The manipulator was idealized to be used on pipes with more than 305 mm (12 inches) in diameter and with more than 300 mm in distance between pipe and surface, Figure 8. With the objective to optimize the process execution time in welding of higher diameter pipes, the use of a pair of manipulators to weld the same groove at the same time was idealized, Figure 9. So, while a manipulator makes the ascendant movement welding the groove, the other makes the descendant movement in order to position it for the next weld pass. This prevents the closed arc time in the process while one manipulator goes down, since during all the procedure at least one of them will be welding.

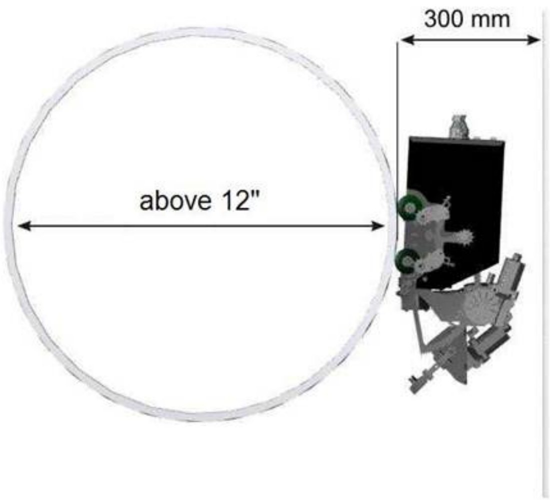


Figure 8. Simulation of distances between pipe and surface.

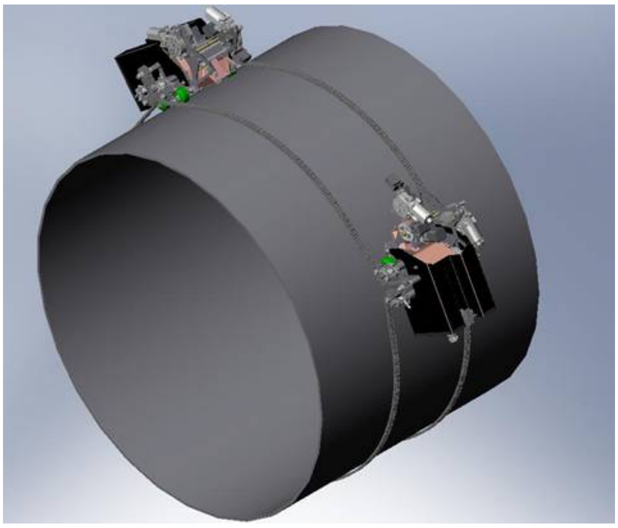


Figure 9. Simulation of welding large pipes using two manipulators

3. PIPELINE ORBITAL WELDING USING ROBOTIC SYSTEM

Pipeline welding is orbital because the torch moves around the pipe while it stays in the same position. With this procedure, it is possible to find different welding positions: plane, vertical up, vertical down and over head. There is a large group of parameters for each of these welding positions.

Both GMAW and FCAW processes are very productive, since wire feed is continuous. The possibility of using a tubular wire (FCAW) for pipeline welding, including the root pass, was analyzed (Soraggi, 2004). The fundamental point to get root pass quality with the robot is guaranteeing the repeatability of the bisel preparation. Figure 9 shows the thickness differences found in the nose of the groove made by equipment that is not automatic.

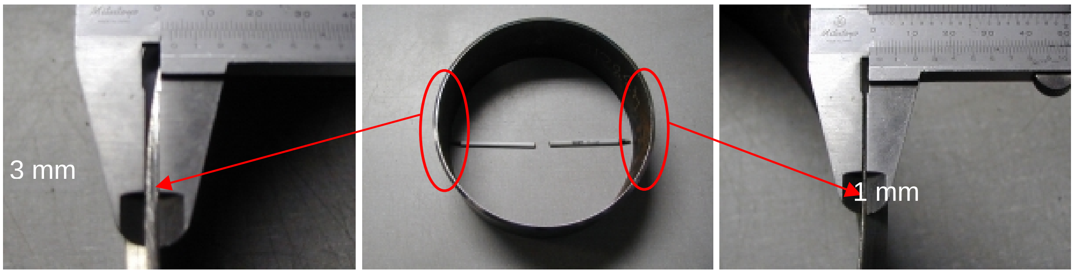


Figure 10. Groove with differences in the nose.

During manual welding the welders can do the corrections in the travel speed and the torch angle, depending on the differences, producing acceptable root passes. The robot, however, can not see and since all the parameters are defined beforehand, large differences are found in the bisel, surely the weld will be reproved. The bisel preparation must then be of high quality before the welding operation is executed by a robotic system with success. Repeatability in bisel preparation is very important. Specific automatic equipment has to be projected and produced to guarantee the repeatability and to facilitate the use of the robotic system. An alternative is to execute the root pass manually and the filling and finishing passes with the robot. Figure 11 shows a filling pass made with the robotic system and Figure 11 shows the finishing pass. In these figures one can see the excellent slag detachability which is the result of the excellent deposition.

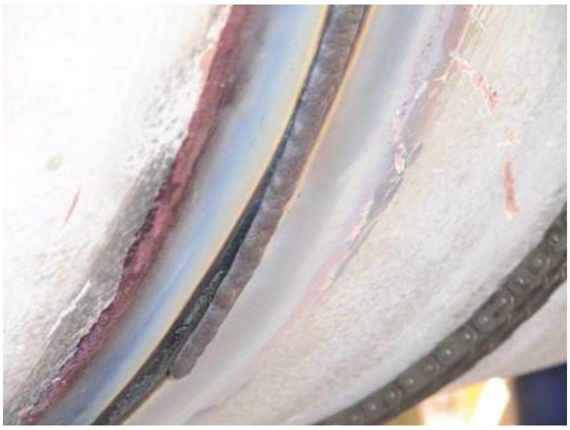


Figure 11. Filling pass made with robotic system. Detail to the slag.

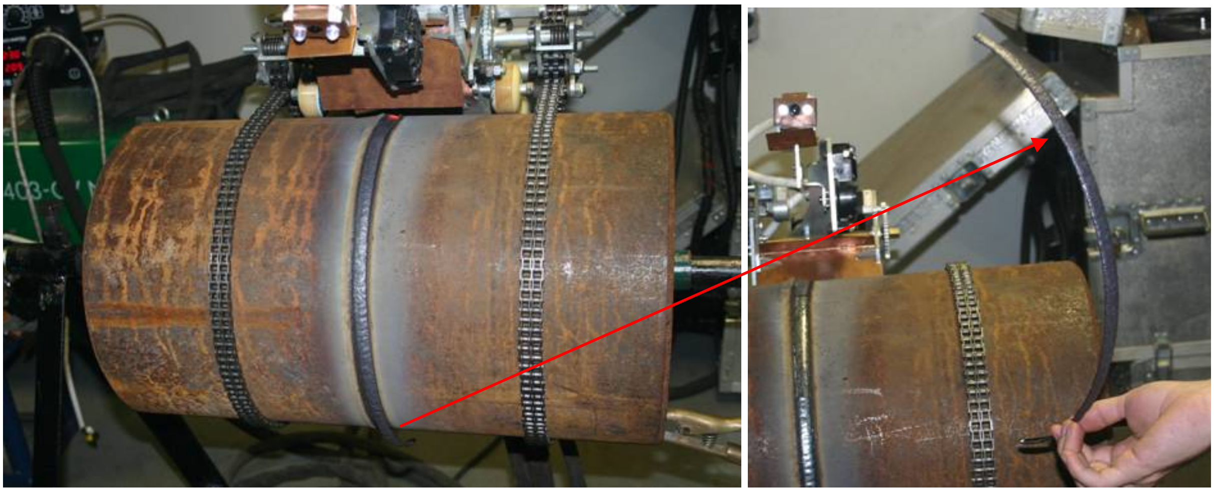


Figure 12. Finishing pass made with robotic system. Detail to the slag.

4. QUALIFICATION OF A ORBITAL WELDING PROCEDURE USING ROBOTIC SYSTEM

The robotic system was shown very efficient. There was a significant increase in weld quality and productivity. The welding procedure was qualified. The pipe welded had 500 mm (20 inches) in diameter with 15 mm of thickness wall.

The project standards used for the qualification were B31.4 for oil pipeline in industrial instalation following the welding standards ASME IX – 2003 Ad. 2005 and in field following the welding standards API 1104 – 1999 and B31.3 for refinery and pipeline in industrial instalation following the welding standards ASME IX – 2003 Ad. 2005.

The mechanical tests accomplished were tension, bending, hardness, macrograph and nick break. Table 1 shows welding consumables used of the tests, Table 2 shows the welding parameters used for ASME IX and Table 3 for API 1104.

Table 1. Welding consumable.

1. Consumable	ROOT	FILLING	FINISHING
Especification	SFA 5.18	SFA 5.20	SFA 5.20
Classification	ER 70S-3	E 71T-1	E 71T-1
Diameter (mm)	3,18	1,2	1,2
2. Process	GTAW	FCAW	FCAW
3. Gases	Argon	Argon + CO_2	Argon + CO_2
Mixture	99,99%	75% Ar + 25% CO_2	75% Ar + 25% CO_2

Table 2. Electric characteristics – ASME IX.

Electric characteristics	ROOT	FILLING	FINISHING
Type of current	Continue	Continue	Continue
Polarity	Direct	Inverse	Inverse
Voltage (V)	11,0 a 12,0	23,0 a 24,0	23,0 a 24,0
Current (A)	132 a 145	160 a 185	170 a 205
Travel speed (cm/min)	4, 5 a 15,5	22,5 a 31,7	23,5 a 31,5

Table 3. Electric characteristics – API 1104.

Electric characteristics	ROOT	FILLING	FINISHING
Type of current	Continue	Continue	Continue
Polarity	Direct	Inverse	Inverse
Voltage (V)	12,0 a 13,5	23,0 a 23,5	23,0 a 23,5
Current (A)	130 a 160	165 a 175	160 a 180
Travel speed (cm/min)	6,35 a 14,0	29,0 a 31,5	29,5 a 31,5

Tension test were accomplished in the base metal without weld and weld metal. The yield point was 347 MPA and the tensile strength was 498 MPA. Table 4 (API 1104) and Figure 3 (ASME IX) show results of the tension tests in the weld joint. Table 5 and Figure 14 show results of the bending test, Table 6, hardness test and Table 7, nick break.

Table 4. Tension test – API 1104.

Sample	Width (mm)	Thickness (mm)	Área (mm^2)	Load (N)	Tension (MPA)	Position of the Rupture
T - 01	24.71	14.64	361.75	174.558	482.54	Base Metal
T - 02	25.25	15.39	388.60	170.635	439.10	Base Metal
T - 03	25.00	15.08	377.00	173.578	460.42	Base Metal
T - 04	25.09	15.34	384.88	180.442	468.83	Base Metal

Figure 13. Tension test – ASME IX.

Table 5. Bending test – API 1104.

Sample	Width (mm)	Thickness (mm)	Discontinuity	Sample	Width (mm)	Thickness (mm)	Discontinuity
D – 1	13.04	12.96	NA	D – 5	13.11	12.96	NA
D – 2	13.10	12.90	NA	D – 6	13.21	13.13	NA
D – 3	13.03	12.91	NA	D – 7	13.06	13.04	NA
D – 4	13.00	12.82	NA	D – 8	13.19	13.13	NA

Type: lateral; knife diameter: 38 mm and bending diameter: 180º.

Figure 14. Bending test – ASME IX.

Table 6. Hardness test – API 1104.

Point	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
Line 1	188	208	212	229	232	244	246	223	214	210	137.2	NA	NA	NA	NA	NA	NA	NA	NA
Point	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38
Line 2	193	214	214	221	260	251	227	262	234	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA

Vickers hardness; Load: 50N

Table 7. Nick break test – API 1104.

Sample	Width (mm)	Thickness (mm)	Discontinuity	Sample	Width (mm)	Thickness (mm)	Discontinuity
NB - 01	19.59	14.23	NA	NB - 03	19.76	15.20	NA
NB - 02	19.38	14.98	NA	NB - 04	19.08	14.14	NA

The quality of the welds was above the expected. Figure 15 shows macrograph of the weld. Figure 16 shows one of the amazing results of the nick break test. As can be observed the sample did not break in the weld. Even with the notch. Of course it was not expected and after many attempts and finally using liquid nitrogen the broken weld surface could be observed for the qualification, the transveral section did not show discontinuity, Figure 17.

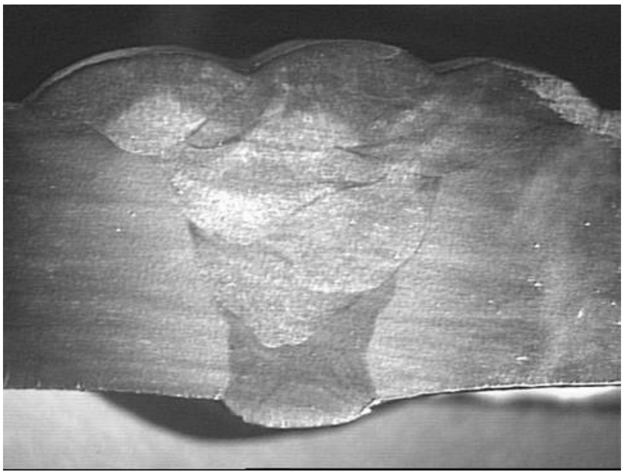


Figure 15. Macrograph – ASME IX.

Figure 16. Result of the nick break – ASME IX.

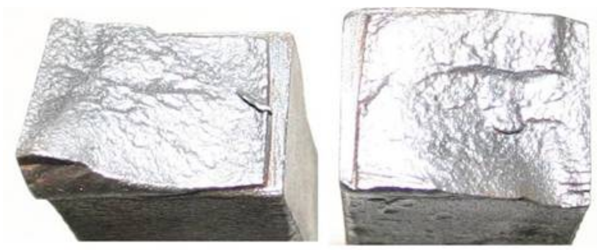


Figure 17. Transveral section of the sample ruptured by shearing in the nick break test – ASME IX.

The quality was even above the manual welds performed before with qualified welders and following specific welding procedure. This result assured the good use of the robot.

The main advantages found with the robotic system for pipeline orbital welding were:

- Quality: the control of the welding parameters during the process provides a more homogeneous weld bead all over its length, independent of the welding position.
- Repeatability: the robot always provides similar welds, increasing the process repeatability, while the robotic system is capable of adjusting to parameters and movements in order to compensate variations in the environment (better noise rejection).
- Economy: rework reduction through the quality and repeatability increase.

- Reduction of weld execution time: the possibility of optimization of welding parameters (welding current, electric arc voltage, stick-out and torch angel) allows the use of greater welding speeds than the normally used in the manual welding.
- Increase of the open arc time: reducing the total welding time.

5. CONCLUSION

The robotic system for pipeline orbital welding brings enhancement in the final product quality, considerable increase of the repeatability, reduction of rework and reduction of the weld execution time. At the very least, the robot is capable of reproducing the work (the weld bead) of the best human welder, through the use of the same parameters contained in a reference table. Moreover, it is possible to optimize such parameters, in order to further increase the quality and to reduce the weld execution time through the welding speed increase.

In pipes with larger diameters, it is even possible to use two robots simultaneously, decreasing even more the close arc time, increases the work factor.

6. ACKNOWLEDGEMENTS

The authors are grateful to the Federal University of Minas Gerais for its technical support and Service Engenharia Ltda and Rotech Tecnologia Robótica Ltda for their support in the design, construction and implementation of the robotic system for pipeline orbital welding.

7. REFERENCES

API Standard 1104, “Welding of Pipelines and Related Facilities”, American Petroleum Institute, Nineteenth Edition, 1999, pp. 1-70.

Bracarense, A.Q., Felizardo,I., Lima Ii, E.J., Torres, G.F., Ramalho, F. Zanon, G.P, “Sistema Robotizado para Soldagem Orbital de Dutos”, Rio Oil & Gas Expo and Conference, Rio de Janeiro, 2004.

Lima II, E.J., Torres, G.F., Felizardo,I., Ramalho, F. Bracarense, A.Q., “Development of a Robot for Orbital Welding of Pipes”, Musme - The International Symposium On Multibody Systems And Mechatrocnics, Uberlândia, 2005.

Felizardo, I, Bracarense, A.Q., Lima II, E.J., Torres, G.F., Reis, A.T.C, Papatela, P.H.C, “Soldagem Orbital de Dutos Utilizando Robô Dedicado de 4 Graus de Liberdade”, Congresso Iberoamericano de Engenharia Mecanica, México D.F., 2005.

Rivin, E, “Mecahnical Design of Robots” Mcgraw-Hill Inc., First Edition, New York, 1988.

Soraggi, C. C., “Estudo Paramétrico para Robotização da Soldagem Orbtial de Tubos com Arame Tubular”, Dissertação de Mestrado, Departamento de Engenharia Mecânica, Universidade Federal de Minas Gerais, Belo Horizonte, 2004.

8. RESPONSIBILITY NOTICE

The authors are the only responsible for the printed material included in this paper.