DETERMINATION OF STRAIGHTNESS ERRORS IN A WELDING ROBOT

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Abstract: In some large industries, a robotic arm describing predefined paths in work volume and carrying a welding gun executes automatic welding operations. The deviations in relation to ideal robot arm predefined paths may cause severe distortions in welded parts. The displacement along a straight path must be close to the ideal straight line and the deviations cause a poor quality weld. In this case, the straightness errors in two orthogonal planes crossing the planned welding line can be considered as parameters to predict welding quality. In this work, an approach was used to investigate the performance of a welding cell that requires the determination of path straightness of a robot arm movement using online programming. This approach involves the use of a dial gauge connected to the robot arm and moved over a reference straight standard. The straightness was determined as the range of the measurement errors at each measuring line and was determined in several different locations in work volume. The results obtained showed that the different regions in work volume promote the change in weld quality and error compensation may be applied to improve the accuracy in welding operations.

Keywords: straightness, robot performance, welding cell performance

1   INTRODUCTION

Nowadays, the welding process is largely used in industry to join metallic pieces like that of automobiles, ships and airplanes. Since this process is realized through the heating and or pressurizing the components, the different welding process may be classified according to the method of heat generation: electric arc, resistance, solid state, radiant energy, thermit and gas welding. The arc welding process is a largely used process in which an electric arc is established between an electrode and a workpiece to heat generation. The heat source is directed at the piece region and it may be required the deposition of a welding metal [1].

A particularity of all these processes is that a welding gun is displaced over the part junction to heat generation and welding the parts. An operator may realize this work but the process automation is generally carried on using a robot arm to guide the welding gun along predefined paths and improving the productivity. An additional advantage of this construction is the flexibility of welding fabrication, since different welding paths may be established at welding cell.

An automatic welding cell construction is showed in fig.1 and is located at GRACO - Automation and Control Group of Manufacturing Processes at University of Brasília. This welding cell has a robot that guides a welding gun through the robot working volume. There is a welding unit that operates the welding gun. There is a control unit linked to a computer that controls the robot arm displacement. The robot arm movement may be executed through a computer program (off-line programming) or using a joystick (online programming). The off-line programming allows complicated welding operations without the interruption of the fabric operation since a computer program is constructed using a computer, but it requires the robot calibration to compensate the positioning error. The online programming is largely applied since it may be applied without robot calibration [2].

In many welding operations, the path followed during process is a straight line. In this case, high quality welds are related to the degree of the straight line can be followed by the robot arm displacement. In arc welding processes, deviations in relation to straight path leads to variations in the gap between the welding gun and the workpiece and the electric arc instability imply in defects at the welded junction. Besides, the straightness at workpiece plane may cause irregularities at junction

contact points and result in lack of mechanical properties. The investigation of the straightness must be realized to predict these problems since it is possible to compensate these errors [3].
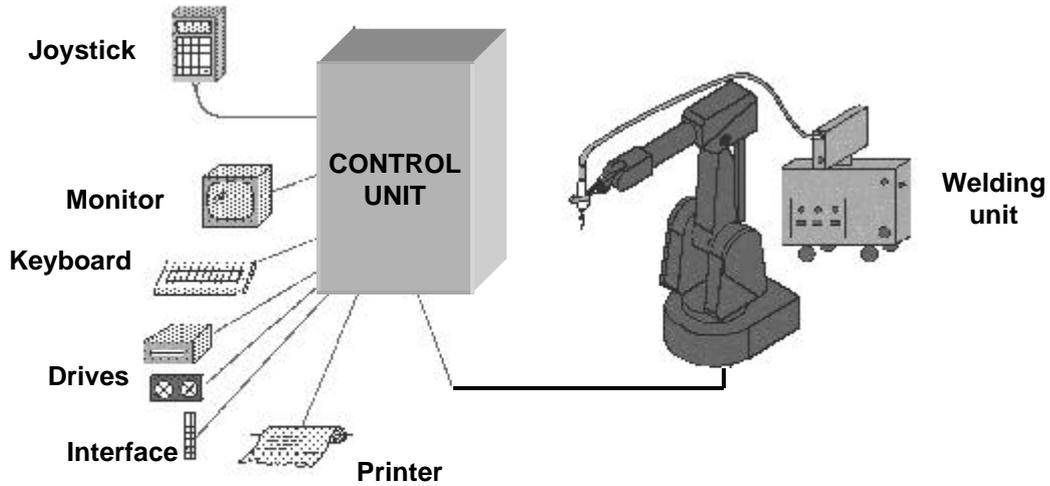

Figure 1. Scheme of the welding cell

This work proposes an experimental study to investigate the performance of a welding cell when using online programming. The performance was verified determining the straightness in the straight paths performed by a robot arm when realizing arc welding operations. The study was accomplished measuring the straightness along different straight lines in the robot workspace. The experiments were carried out with a dial gauge and granite straight standard. The errors were determined through the variation of straight path in two orthogonal planes along each straight line path.

2   STRAIGHTNESS IN ROBOT ARM DISPLACEMENT

The word straightness designates the disagreement of the real path of a moving object in relation to an ideal straight line. It may be quantified by measuring the deviations in relation to a straight trajectory using instruments like laser interferometer, dial gauges and autocollimator. Its determination is necessary when calibrating machine tools and Coordinate Measuring Machines, since the machine tool moving carriage and the Coordinate Measuring Machine probe follow straight trajectories along its reference axes.

The robot arm at welding cell may be handled to describe straight paths. In this case, the robot arm must describe a real path close to the ideal one to promote high quality weld. This occurs because the parts are located at a fixed position and a welding gun displacement different from the planned path can result in irregular welds that produces variability in mechanical properties of the junction. The ISO 9283 Standard describes methods of testing path accuracy in robot movements [4] and there are actually some researchers investigating robot calibration methods [5, 6] intending to compensate these errors.
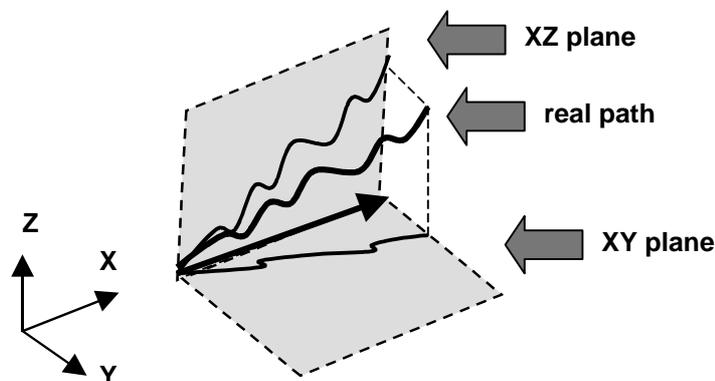

Figure 2. Straightness in XZ and XY orthogonal planes, when moving along robot X-axis.

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Thereby, straightness in robot arm displacement can be considered as a parameter to predict the quality of the welding when producing welds along straight paths. The ideal straight line is desired and must be planned online through plotting the first and last point with robot joystick. The errors associated to robot arm displacement along the robot X-axis planned path may be seen in fig. 2. In this figure, the straightness of this path may be decomposed in two orthogonal planes, XZ and XY, according to robot coordinate system. Thus, there are two straightness errors in each path followed that may be experimentally determined [3].

3   EXPERIMENTAL TESTS

The investigation of the welding cell performance was realized at University of Brasília, at GRACO Laboratory. The welding cell has an Asea Brown Bovery IRB 2000 robot that moves the welding gun along a work volume. The robot resolution is 0.125 mm and the repeatability is 0.1 mm. The robot displacement velocity was held at 30 mm/s. Online programming was used to move the robot arm along the desired straight paths.

The straightness errors were determined using dial gauge and granite straight. The straightness standard was a RHAN straight, with 1.37 µm straightness and a MITUTOYO Dial Gauge with 10 µm resolution and uncertainty of 50 µm were used to determine the differences in relation to straight paths. During the experimental trials, the temperature was changing at 28±2 $^{\circ}$C. The uncertainties of the straight and Dial Gauge were very small when compared to the determined errors and thus were ignored.

The experimental construction was accomplished positioning the granite straight aligned to each X, Y or Z robot axis. The Dial Gauge was held by the robot arm using a device as showed in fig. 3 and it was oriented at the X, Y or Z-axis depending on the straightness measurement direction. The granite straight was positioned in several locations along work volume and after mechanical alignment the errors were determined at the two orthogonal planes crossing the virtual line followed.
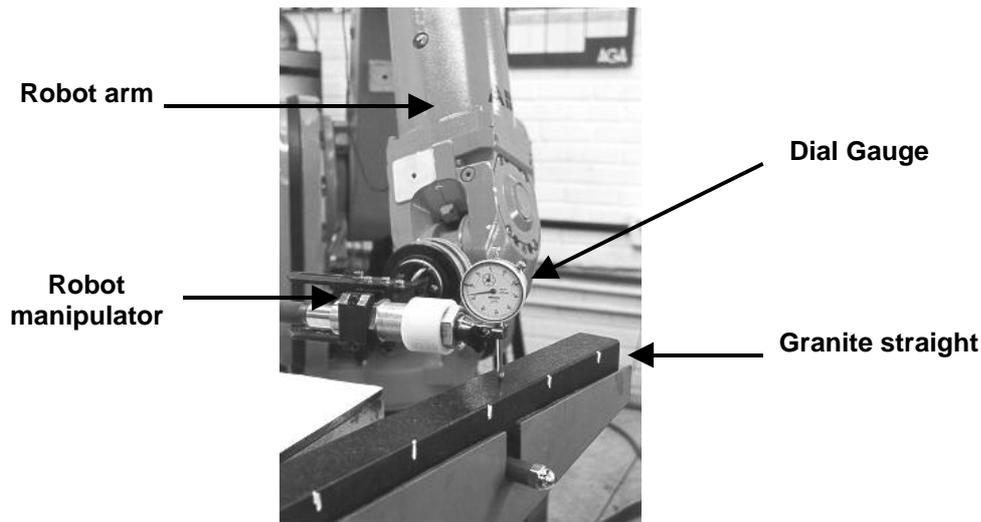

Figure 3. Experimental construction to determine straightness

The straightness along 22 different paths in the robot work volume was investigated. These paths are represented fig. 4. The Dial Gauge was displaced along 800 mm straight path over each line represented and the error was recorded at each 100 mm step subdividing the straight line followed and at two orthogonal planes crossing the reference line. At each straight line, the errors were determined moving the dial gauge forward and backward to verify the hysteresis. Five error replicates were determined at each measured point in each plane to estimate the variability of the results.

Since there were errors associated to lack of alignment between robot axis and straight standard and provided that these systematic errors may be compensated, the straightness was determined considering the straight line established by the first and the least point measured as reference in given path. Thus, the graphics were constructed plotting the mean in each trajectory (forth and back) and including a 95% confidence interval using two standard deviations in each curve (forth and back). The straightness was considered as the error range plotted in the graphic and the hysteresis was determined by the difference between the forth and back mean curves.

The results were compared each other and with the catalog information about the robot operation to establish the performance of the welding cell. The permissible variations admitted during welding were compared to straightness errors determined. The effect of loading a robot arm was investigated.
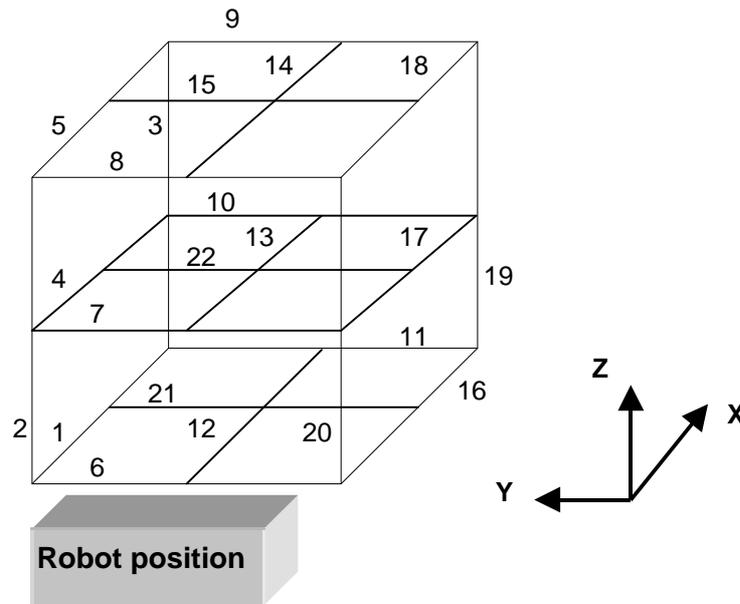
Figure 4. Welding paths investigated in robot work volume

4   RESULTS AND DISCUSSION

The errors determined using a Dial Gauge were plotted in graphics, as shown in fig. 5. The straightness was determined as the range of the errors in each graph. The hysteresis was determined as the maximum difference between the forward (black) and backward (gray) mean curves and the path repeatability was determined as two standard deviations (95% confidence) at the backward or forward curve.

Fig. 5 show the errors determined at XZ plane when the robot arm movement was along the X-axis (position 1). The first graph is related to the unloaded condition and the straightness was 1300 µm, the hysteresis was 350 µm and the path repeatability was 100 µm. When the robot arm was loaded with 50 N, the straightness at the same position and plane was 1500 µm, the hysteresis was 400 µm and the path repeatability was 100 µm. When the load was 100 N, the straightness was 1500 µm, the hysteresis was reduced to 200 µm and the path repeatability was 100 µm. The increase in straightness and decrease in hysteresis as load increase was observed always measuring at XZ or YZ plane. When measuring at XY plane (horizontal), the load did not affect the straightness, hysteresis and path repeatability.

Since the welding gun weight is equivalent to 50 N loading, this load condition was used to compare all others horizontal and vertical planes behavior. Then, it was observed at position 1 and plane YZ that straightness was 220 µm, hysteresis was 110 µm and path repeatability was 100 µm. These straightness and hysteresis values were smaller than at XZ plane and path repeatability values were similar.

The path repeatability was nearly the same at all different positions measured. Besides, the hysteresis affects the straightness results because it is included in straightness determination. Thus, it was considered only the straightness at the sequence of this analysis.

The robot arm movement along robot X-axis (position 1) begins with the robot arm retracted at coordinate system origin and it is extended during the movement along the path. There are other positions where the robot arm junctions movement is realized at X-axis like position 1 and these are the positions 4, 5, 12, 13, 14, 16, 17 and 18. However, it was observed some differences in straightness at XZ plane using 50 N loading. The smaller straightness was at position 5 and it was 350 µm and after that at position 13 it was 450 µm. The bigger straightness was at position 12 and it was 1900 µm. At position 5 and at horizontal XY plane, the straightness was 330 µm and at position 13 and horizontal XY plane the straightness was 260 µm.

The positions 6, 7 and 8 located at Y-axis direction require robot arm retracted. The straightness at YZ plane was respectively 400 µm, 440 µm and 500 µm. The straightness at XY plane was 260 µm, 180 µm and 300 µm. At the other side of work volume, the positions 9, 10 and 11 requires robot arm totally extended and displacement along Y-axis. The straightness was respectively 1700 µm, 1600 µm and 1600 µm at YZ plane and 310 µm, 220 µm and 230 µm at XY plane.

The analysis in respect to Y-axis displacement showed that the smallest straightness values were determined at vertical planes when the robot arm was retracted (positions 6, 7 and 8). The straightness at horizontal planes was not affected by robot arm condition. Similar results were

observed at Z-axis positions 2, 20, 3 and 19, when straightness was respectively 300 µm, 320 µm, 650 µm and 700 µm at XZ plane, that were closed to YZ plane straightness results.
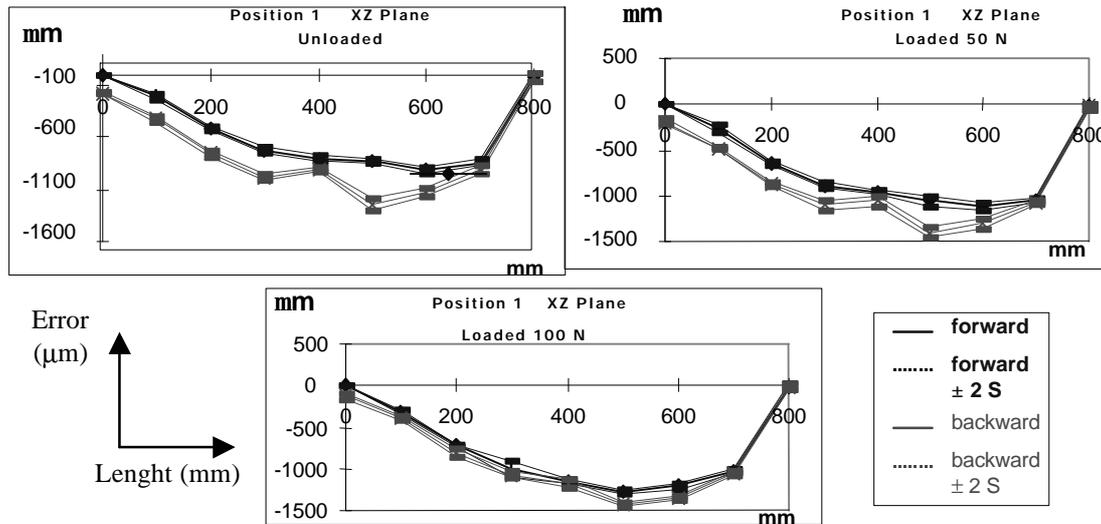

Figure 5. Straightness errors in plane XZ, when measuring along X-axis (position 1)

5   CONCLUSION

The experimental results showed that the procedure used was suitable to investigate the viability of welding in welding cells at low cost. It was observed the best and worst positions to realize welding operations.

Despite the repeatability observed was nearly the same stipulated by robot manufacturer, the straightness errors determined can make unfeasible welding operations in some locations at work volume. The best way to realize welding operations is following paths along Y-axis when the robot arm is retracted (positions 6, 7, 8, 2 or 20). The welding along the Z-axis (positions 2 and 20) may be realized with some increased straightness errors in respect to Y-axis. If it is not possible following these paths, it is recommended to follow the paths 5 or 13 because the straightness was at its smallest values at X-axis.

To prevent bad quality weld execution it is recommended the robot calibration to obtain robot arm displacement closed to ideal straight paths. Future works may be suggested to investigate different paths like circular path and the use of off-line programming.

6   ACKNOWLEDGEMENTS

REFERENCES

[1] R.S. Parmar, *Welding Processes and Technology*, Khanna Publishers, Delhi, India, 1995, 760 p.
[2] G.C. Carvalho, S.C.A. Alfaro, M.L. Siqueira, Off-line programming of flexible manufacturing cells, *Journal of materials Processing Technology*, 1998.
[3] A.D.A. Gómez, *Performance evaluation of a robotic welding cell*, University of Brasília, Brasília, 1999. (In Portuguese)
[4] ISO 9283, Manipulating industrial robots - performance criteria and related test methods, 1990.
[5] G. Simon, Optotrac - cat's eyes and lasers, *Industrial Robot* 21 (6) (1994) 18-21.
[6] M.R. Driels, W.E. Swayze, Automated partial pose measurement system for manipulator calibration experiments, *IEEE Transactions on Robotics and Automation* 10 (4) (1994) 430-440.

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