Three-dimensional Simulation of Robot Path and Heat Transfer of a TIG-welded Part with Complex Geometry

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Abstract: The applications of commercial software Off-Line Programming (OLP) packages for robot simulation, and programming, us interactive computer graphics, provide powerful tools for creating welding paths off-line. By the use of such software, problems of robot reach, accessibility, collision and timing can be eliminated during the planning stage. This paper describes how such software can be integrated with a numerical model that predicts temperature-time histories in the solid material. The objective of this integration is to develop a tool for the engineer where robot trajectories and process parameters can be optimised on parts with complex geometry. Such a tool would decrease the numer of weld trials, increase productivity and reduce costs. Assumptions and principles behind the modeling techniques are presented together with experimental evaluation of the correlation between modeled and measured temperatures.

Keywords: Off-Line Programming(OLP), Simulation, CAD/CAM

1 Introduction

The metallurgical structure of a metal, which determines its mechanical properties, is a function of its chemical composition, its initial structure and the thermal effects of the welding process. Theoretically, if both the thermal events and the response of the material to the thermal process is known, the resulting changes in microstructure and properties can be predicted. Several papers have been Publisher concerning numerical modeling of thermal histories, residual stresses, and distortion. Mainly two-dimensional studies have been performed. Threedimensional studies are still restricted to simpler shapes such as plates and pipes.

The use of robots for arc welding started in the early 70´s and is now extensively used in the MIG/MAG processes. Using robots for Tungsten Inert Gas (TIG) welding is however still rare. One of the reasons is the increased demand for precise programming and control. Programming of welding robots is usually done manually by the jog teach method. Using this method the robot is off-line, the part stationary, and the robot arm jogged through the program under reduced power and at reduced speed, via a joystick. Generating a path by hand in this way can be time consuming. On a complex geometry, it is virtually impossible for a programmer to maintain constant gun velocity, distance from, and orientation to, the part. However, by using computer simulation this problem can be overcome. Using this method, the programming is moved away from the robot to a graphical computer system, often referred to as a “off-line programming” system. The technology in this area is well established and has been a research area for some ten years. Despite these extensive investigations, the two different simulation techniques (numerical process modeling and OLP) seems only to have been studied separately. The objective of this program is to provide temperature - time histories and metallurgical- and mechanical-properties predictions on robot welded parts. The program is divided into four parts:

1. to off-line program parts with complex shapes,
2. to numerically predict the shape of the molten pool by the use of Computational Fluid Dynamics techniques,
3. to numerically solve the energy equations in the solid material with sufficient accuracy that metallurgical predictions can be made, as well as to link the off-line programming model with this numerical model,
4. to empirically establish relationships between temperature-time history and metallurgical and mechanical properties.

2 Principle of Off-line Programming and Integration of the Heat Transfer and Off-line Programming Models

Several commercial software packages for off-line programming of robots exit (CATIA, IGRIP, Robcad). A brief description of the metodology using such systems is given below.

The methodology of Off-Line Programming includes the following steps:

1. modeling of the work cell,
2. modeling of the work-piece,
3. calibrating the work-cell,

4 adjusting and fine-tuning up and down loading of programs,

5 programming,

6 test runs and macro programming enhancements

The first step to model the work cell concerns the construction of a geometric and a kinematic model of the robot, positioner etc. This demands access to design drawing of the cell together with measurements of critical dimensions in the cell. The workcell model is usually constructed directly in the Off-Line Programming system. The Interactive Graphics Robot Instruction Program, Deneb Robotics system was used in this study. In the second step a geometrical description (CAD data) of the part to be welded is generated either in a CAD/CAM software or in the off-line programming software. If this model is created in a CAD system the data is imported to the Off-Line Programming software either using a neutral interface or a direct reader.

The accuracy of the modeled workcell is usually not high and the third step is therefor to make a calibration by measuring different points in the physical welding cell. This procedure might include several sub-steps depending on the komplexity of the workcell. In this work a tool calibration and a calibration of the workpiece were performed. Tool calibration is performed to determine the tool center point and to determine the orientation of the weld torch. The procedure used in thisn study was to have a measuring arrow in a fixed position in the work cell and to move the robot to this position in different directions. The positions from the real robot cell were then uploaded to the Off-Line Programming software and a “best fit” was performed by the system. The calibration of the workpiece was performed similarly by noviny the robot to clearly identified positions on the workpiece. These positions were recorded and uploaded to the Off-Line Programming software where the difference between model and measurements was calculated and an adjustment of the model using lest squares fitting was done. The motion of the robot is then programmed in steps four and five, either in a high level programming language or in a specific robot language.

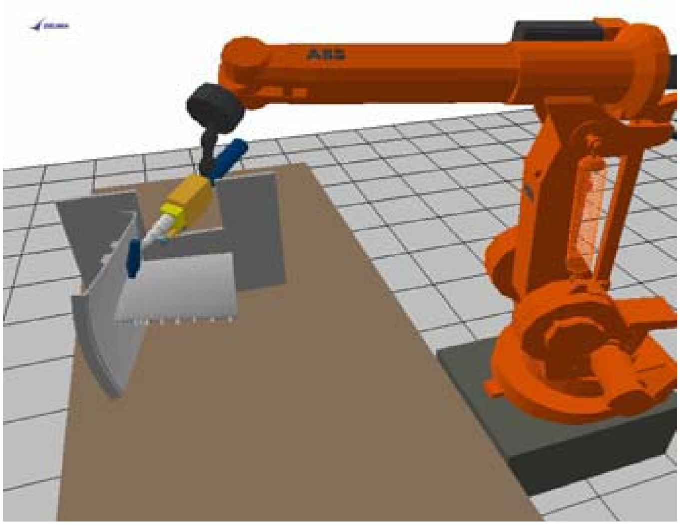

Figure 1
Off-Line Programming *model.*

A robot trajectory is then defined by a set of coordinate frames specifying locations and gun orientation. After that, the motion may be simulated to check the results on the computer. High level languages are then translated and the program finally downloaded to the robot controller where in the final step, test runs are performed. Figure 1 shows a screencapture during the simulation in the Off-Line Programming system.

By the integration of the heat transfer model above with the off-line programming systém Interactive Graphics Robot Instruction Program (IGRIP), a powerful, yet efficient tool for temperature prediction and optimization may be obtained. To that end, an interface translating the data; robot coordinates, welding speeds and currents between the two softwares was developed. This interface calculates a linear motion between each robot point, which controls the moving heat source in the finite element calculation. The two softwares (IGRIP and Marc) have to be installed on the same workstation since communication between different operating systems has not been considered.

The method to program robots off-line described above has been used in this study. An in house welding cell, see figure 2, was modelled in IGRIP (Interactive Graphics Robot Instruction Program, Deneb Robotics).

Figure 2
Interactive Graphics Robot Instruction Program *model*

Conclusions

Research in arc welding simulation can be divided into two main fields, namely robot simulation, often refereed to as CAR (Computer Aided Robotics), and thermal-mechanical modelling. CAR concerns simulation and programming of a robot task using a virtual model of the workcell and the part to be welded. Examples of research in this area are the integration and development of virtual sensors and the optimisation of welding sequences and torch trajectories to ovoid collisions and to increase productivity. Thermal-mechanical modelling concerns the modelling of the influence of the process on the component. It includes the prediction of temperature histories, microstructure phase transformations, residual stresses and distortion.

This thesis addresses both these areas, i.e., both CAR and thermal-mechanical simulations, through the integration of an off-line programming system with a Finite Element Analysis (FEA) system. CAR is used to simulate Tungsten Inert Gas torch paths and to detect collisions between the torch and workpiece. FEA is used for the prediction of temperature histories and residual stresses and the optimisation of welding parameters as regards penetration.

An engineering method and a simulation tool to define robot trajectories and to predict thermal histories on parts with complex geometries have been developed. The method was evaluated on a part with a complex shape where robot weld paths were defined off-line, and automatically downloaded to a Finite Element Method (FEM)-model where transient temperatures were predicted. These predictions were compared with experimental measurements using both thermocouple and infrared emission measurements and good agreement was found. The described method provides a promising means to construct and optimise torch trajectories and process parameters off-line. Using this system, thermal histories can be predicted on complex shaped parts and thereby resulting changes in microstructure and mechanical properties be estimated. The models used may after futer development enable the optimization of welding processes, thus increasing productivity and reducing the need of weld trials.

Reference

[1] Mikael Ericsson: Simulation of robotic TIG-welding. Sweden 2003

[2] Gu, M.; Goldak ,J.; Hughes, E. 1993. Steady state thermal analysis of welds with filler metal addition. Canadian Metallurgical Quarterlv. 32 (1): 49-s to 55-s

[3] Lindgren, L. E.; Karlsson, L. 1988. Deformation and Stresses in welding of Shell Structures. Int. J. for Numerical Methods in Eng. 25: 635-s to 655-s

[4] Buchal, R. O.; Cheras, D. B.; Sassani, F.; Duncan J. P. 1989. Simulated Off- Line Programming of Welding Robots. Int. J. of Robotics Research 8 (3): 31- s to 43-s

[5] Walter S. 1994. Simulation and Calibration for Off-line Programming of Industrial Robots. Proc. of Computer Technology in Welding: Paper 54. Paris 15-16 June

[6] Walter S. 1994. Simulation and Calibration for Off-line Programming of Industrial Robots. Proc. of Computer Technology in Welding: Paper 54. Paris 15-16 June

[7] Bolmsjö, G.; Olsson, M.; Brink, K. 1997. Off- line programming of GMAW robotic systems – a case study. Int. J. for the Joining of Materials, 9 (3): 86-s to 93-s

[8] Bolmsjö, G.; Olsson, M.; Brink, K. 1997. Off- line programming of GMAW robotic systems – a case study. Int. J. for the Joining of Materials, 9 (3): 86-s to 93-s

[9] Daneshjo, N.: Integration of product and process development using CAD systems. 2nd Slovakian-Hungarien Joint Symposium on Applied Machine Intelligence SAMI 2004, January 16-17, 2004 Herľany, Slovakia