Application of Fuzzy Logic to Spatial Thermal Control in Fusion Welding

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Abstract—This paper considers the problem of sensing and controlling torch position in the pulsed gas metal arc welding (P-GMAW) process. The attitude and positional control described is essential to the production of quality welds with a specified geometry. For constant current arc welding processes, as normally employed with P-GMAW, the arc voltage signal variations that occur as a function of changes in the contact-tube-to-work distance can be used to automatically control the welding system with respect to bead placement and proper sidewall fusion. However, the arc voltage signals are uncertain and noisy because of many inherent disturbances associated with the electrode tip, droplet formation, droplet detachment, and droplet transfer through the arc. Additionally, the welding process’ complex dynamics, nonlinearity, and time variance render traditional control system techniques difficult to apply. To deal with the nonlinear time-varying process with its inherent stochastic disturbances associated with the metal transfer, the theory of fuzzy sets was used as a general framework to interpret the uncertain arc signals and provide logic for control. The fuzzy logic controller weld joint tracking system was implemented and tested with pulsed gas metal arc welds under a variety of conditions. The goal was to obtain quick and accurate response to tracking errors in the presence of disturbances. A series of experiments was conducted to evaluate the performance of the fuzzy logic controller. The experimental results show that the fuzzy logic controller was found to be suitable for these purposes and better than methods based on signal averaging and bipolar decision levels under these criteria.

Index Terms—Fuzzy logic control, gas metal arc welding process, weld seam tracking control.

I. INTRODUCTION

IMPROVED automation of welding processes has become increasingly important in the push for higher weld quality and reduced manufacturing cost. Robotic welding offers the reduced manufacturing cost sought, but its widespread use demands a means of sensing and correcting for inaccuracies in the part, the fixturing, and the robot.

Among the variety of welding processes available, pulsed gas metal arc welding (P-GMAW) is one of the most frequently used, primarily because it is highly suited to a wide range of applications, and also to automation. A number of problems that need to be addressed in automating arc welding processes include sensing, joint tracking, and lack of adequate mathematical models for parameter prediction and quality control. Problems with parameter settings and quality control occur frequently in the P-GMAW process because of the large number of interactive parameters that must be set and accurately controlled. Moreover, a classical or modern control system design approach is almost impossible to achieve due to complicated dynamics, severe nonlinearity and time variance of the process. Hence, an approach adapted to combating these modeling difficulties is fuzzy logic control (FLC) which provides an approximate but effective means of describing the behavior of the system.

Any complex system may be considered as a fuzzy system whose implementation can be formulated as a search problem in high-dimensional space. Each point in this space represents a rule set, membership functions, and the corresponding systems behavior. According to some given performance criteria, a hypersurface in the space is created. This hyperspace may be infinitely large, nondifferentiable, noisy, multimodal, and deceptive. Finding the optimal location of the hyperspace gives the optimal fuzzy system design [1].

Many industrial applications of FLC have been reported [2], [3]. An important application field where fuzzy logic may play a significant role is in the control of consumable electrode arc-welding processes. For consumable electrode processes, there are three principal types of natural metal transfer that can be identified: short circuiting, globular, and spray transfer. The high current operating mode is spray transfer in which discrete metal droplets are drawn off the wire tip under the strong arc forces and through the arc. At low current levels metal is transferred either by short circuiting (at low voltages) whereby the molten electrode tip periodically contacts the weld pool, or by globular metal transfer (at voltages too high for short circuiting) which is characterized by the detachment of individual droplets whose size is considerably larger than the wire diameter. In the short-circuiting mode, transfer only occurs during the short circuit and its stability is largely determined by the power source settings, the shielding gas, and the material being welded. In all of the modes of operation, the stability of the metal transfer is also influenced by the melting behavior of the electrode tip and the surface tension and viscosity properties of the molten droplet. A common aspect of arc instabilities in these processes has been the inability to identify the cause of the breakdown in the metal transfer or,