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Model reference adaptive controller for enhancing depth of penetration and bead width during Cold Metal Transfer joining process

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ABSTRACT

In this paper, an adaptive control scheme is employed for joining Aluminium 6061 alloy sheets by Cold Metal Transfer (CMT) process. The transfer function model of the CMT welding system is derived using empirical equations. The CMT plant transfer function is estimated using system identification technique. For the estimated plant model, a conventional PID controller is initially designed by tuning the controller parameters. The designed control system is tested for its ability to control the welding current when short circuit phase and arcing phase are detected. Following the conventional PID controller, a Model Reference Adaptive Controller is implemented to maintain the welding current at desired range during melting and electrode wire short circuiting. The performance analysis for the proposed adaptive control scheme and the conventional PID controller is compared. The simulation results indicate that the conventional PID controller is unable to retrieve the desired current during short circuit phase and arcing phase. Nevertheless, the proposed MRAC for CMT process successfully maintains the welding current at the setpoint when subjected to arcing phases and short circuit respectively, while ensuring arc stability. The experimental validation is carried out in the CMT welding set up using the designed MRAC. The experimental results emphasize that the MRAC improves the welding performance by yielding good weld joints swiftly and enhanced quality besides minimizing the design complexities.

1. Introduction

Accomplishment of superior weld quality inevitably demands the process automation. The Cold metal transfer (CMT) welding is comparatively an improvised Gas Metal Arc Welding (GMAW) process designed by the Fronius Company. The process temporarily decouples the electrical arc transients from the electrode feed wire [1]. The CMT process depends on the electrode wire short circuiting for occurrence of the material transfer. The CMT process employs the wire feed for controlling the welding process [2]. The CMT process operates in the short-circuit mode which is characterized by a high current and low voltage. Arc is established between the electrode and the workpiece, which in turn melts the electrode [3]. Once the short-circuit is formed, the current reduces to a lower value and the electrode retracts by detaching the molten droplet as shown in Fig. 1. One of the advantageous feature of CMT is that, the material transfer occurs during the short circuit phase with low heat input.

Aluminium alloys are suitable for applications like automobile parts, marine and ship components, aerospace components, etc., due to its good mechanical and structural properties, light weight and outstanding resistance to corrosion [4]. The fusion welding of aluminium alloy sheets always poses a challenge in the form of Intermetallic compound (IMC) formation and cracks due to uncontrolled excessive heat input from the electrode wire. Being a low heat input process, CMT welding is suitable to weld Aluminium alloy sheets since it results in integrity enhanced good mechanical and microstructural properties [2].

For any welding process, the role of control system has a significant influence on the properties of final weldment such as micro and macro structures, weld bead geometry and mechanical properties. The welding process consists of several time dependant variables, non-

Abbreviations: CMT, Cold metal transfer; GMAW, Gas Metal Arc Welding; PID Controller, proportional integral and derivative controller; MRAC, Model reference adaptive controller; DOP, Depth of penetration

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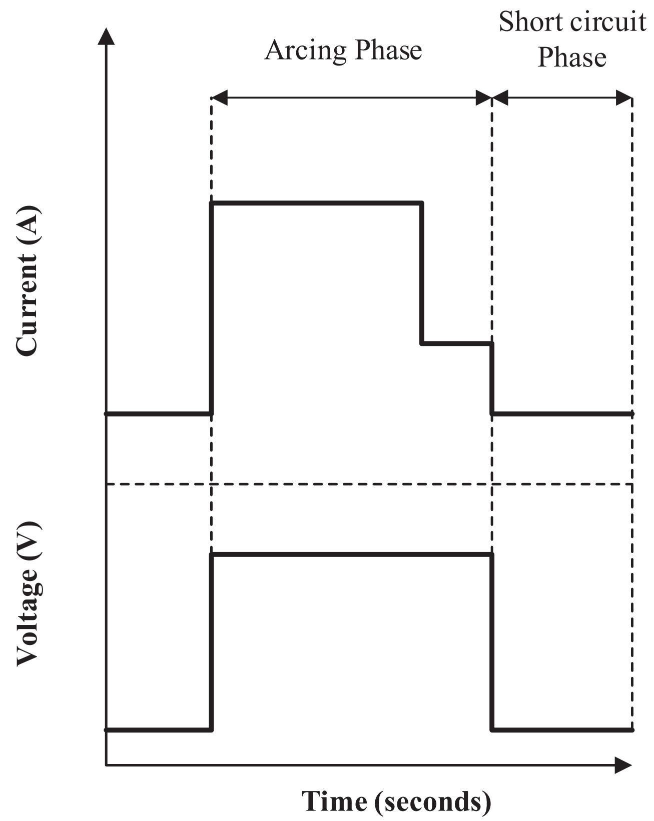

Fig. 1. Arcing phase and short circuit phase in CMT process [3].

linearities and uncertainties due to multiple input and output parameters. A good control system effectively utilizes the resources and prevent material wastage which results in good weldment [5]. Therefore, establishing an accurate mathematical model of the system and opting a suitable control strategy to control the welding process becomes essential in welding process control analysis. Some of the literature addressing the welding control are discussed as follows.

Chae et al. proposed a mixed current and voltage PID control scheme for an inverter-controlled arc welding machine [6]. It incorporates a closed-loop current controller and an open-loop voltage controller to optimize the output voltage and current waveform. An experimental comparison was made between the conventional and newly proposed control scheme (as shown in Fig. 2). It is revealed that the control schemes reduced the spatter generation by 30–50% by stabilizing the metal transfer and improved the welding performance.

Cuiuri et al. developed novel control strategies to improve the control of highly unstable metal transfer in the GMAW process. The research reviewed the issues involved in arc stability with CO_2 shielding [7]. The authors proposed a solution to reduce the spatter levels when the wire feed rate increases. Dominic John Norrish designed a modular programmable GTAW welding controller with graphical user interface (GUI) [8]. The control algorithms were developed and implemented using DSP processors. The welding performance was evaluated readily by comprehensive monitoring capabilities. Mecke et al. [9] developed a closed loop adaptive control strategy to minimise switching losses for a light weight ZVZCS-PS-FB-Convertor built with IGBT's and MOSFETs. Snubber capacitors were used to reduce switch turn-off loss and saturable inductors were used to prevent discharge of the blocking capacitor and to limit the current rise. Guo-rong et al. developed Sliding mode control (SMC) and PI control, based on average state space mode for Arc welding inverter [10]. PI controller was applied for current loop to improve the stability. SMC was applied for voltage loop to decrease the overshoot of voltage loop without affecting the current loop. And phase shift PWM generation was applied additionally for making a simple control and attain superior performance.

Pang and Zhang proposed a Microcontroller (MCF5213CAF80) and FPGA based control system for pulsed MIG welding system which aimed at improving flexibility, control, precision and reliability [11]. The experimental results shows that the microcontroller and FPGA based control system provided quicker response, better reliability and more stable arc length as shown in Figs. 3 and 4.

Skrzyniecki et al. performed an experimental study on power source stability for MIG/MAG welding processes using LabVIEW software and a computer [12]. The computer-controlled process resulted in good weldment as shown in Figs. 5 and 6. The author suggested to prefer advanced methods for recording and online monitoring of data.

Junior et al. performed a comparative study on PID controller results with the fuzzy controller for MIG welding process [13]. The results stated that the implementation of fuzzy controller reduced the resonant frequency problems during welding. Cho and Chun implemented Proportional (P) control algorithm in Resistant Spot Welding to control the electrode movement, which in turn assures higher weld quality [14]. Dondcheol Kim and Sehun Rhee designed a fuzzy controller in Co/Sub2/welding to minimize the disturbance effects occurs during welding. The fuzzy controller stabilizes the arc and makes the control performance robust and insensitive to the in changes operating condition [15]. Panda et al. proposed a numerical modelling method using genetic programming (GP), response surface regression (RSR) and automated neural network search (ANS) to estimate the mechanical properties such as yield strength and modulus of elasticity [16]. The author also characterised the tensile properties of the friction stir welded aluminium joints. The results stated that low input heat results in higher Ultimate Tensile Strength of weldments [17]. The team also investigated the bond strength of the materials and revealed that,

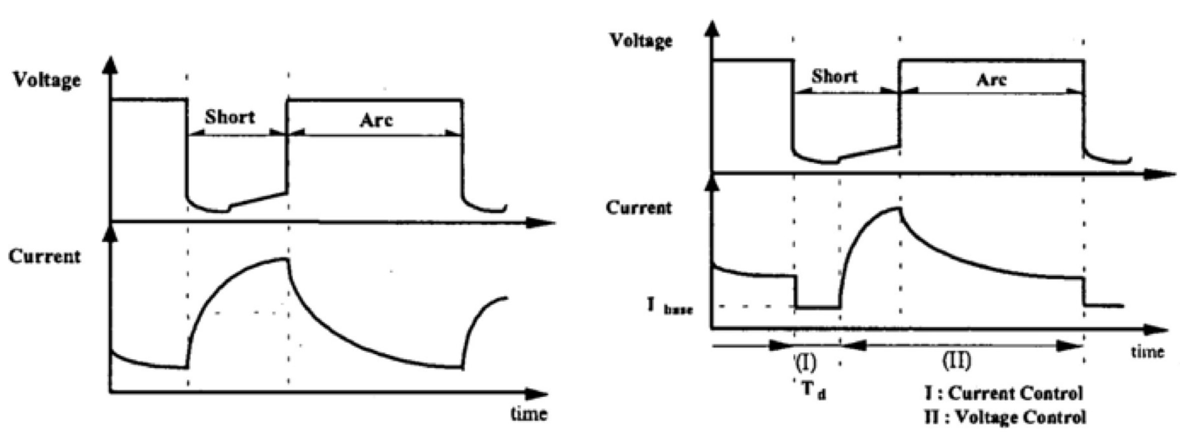

Fig. 2. Output voltage and current waveform of conventional Control scheme (left) and proposed control scheme (right) [6].