Neural Network Model and Control of GMAW Molten Pool Depth with Single-V Groove

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Abstract. An Artificial Neural Network (ANN) model of molten pool depth for Gas Metal Arc Welding process on plate with single-V groove and its intelligent control method are proposed in this paper. That how to select welding parameters as ANN models' input is mainly discussed, and fuzzy theory is used for molten pool depth control. The effectiveness of the proposed methods is demonstrated by the real experiments.

Introduction

The welding process is very complicated, and the weld molten pool depth is the key factor which affects the welding quality [1]. Therefore, the stable molten pool depth must be controlled to get good welding seam quality. As the welding molten pool depth is subject to numerous influencing factors such as welding current and weld groove characteristics, the control of the welding process is not easy.

The control of welding molten pool depth must be based on its mathematical model. The traditional analytical welding models are usually used for welding process analysis; in these mathematical models, the welding molten pool depth is derived directly from the physical laws in the procedure of welding molten pool forming. While in these mathematical models, a number of assumptions are made to obtain the solutions due to the complexity of the welding process. Therefore, it is difficult to depict the welding process with traditional analytical welding models. With the development of artificial neural network, it is widely used in the modeling of various complicate physical processes; it can fit nonlinear function with high precision [2]. Therefore, in this paper, the neural network model of welding molten pool depth is discussed; on the basis of this, the control method of molten pool depth is also discussed.

Neural network model of GMAW molten pool depth with Single-V groove

Gas Metal Arc Welding (GMAW) is widely used for metal manufacturing and forming. In this welding process, an arc is initiated and sustained between a pointed tungsten electrode and the surface of the welded workpiece. Welding wire is drive out continually from welding nozzle by wire feeding device, it melts into groove, and then the welding molten pool forms. At the same time, argon gas is conducted coaxially around the arc and thus it shields the molten weld pool from the atmosphere. In GMAW procedure, the molten pool dimensions have great influence to the quality of welding seam. The unstable molten pool depth is the main factor which leads to the welding structure intension decreases [1,3]. Therefore, in welding control, the main goal of welding control is to keep the molten pool depth stable and suitable.

The molten pool image can be gotten by CCD camera. A typical molten image is shown in Fig.1. The molten pool width W and area S can be got by image processing. Currently, it is difficult to measure the molten pool depth. In fact, such parameters which can not be easily gotten as molten pool width and depth are decided by such parameters which are easily gotten as welding current, welding voltage, torch tip angle, welding speed and grooves. As for welding pool depth, generally speaking, it becomes deeper when welding current increases or groove becomes wider. In addition, assume the input energy and welding speed keep unchanged, when the molten pool width increases, the molten pool depth decreases; when the molten pool width decreases, the molten pool depth increases. Therefore, Artificial Neural Network can be used for describing the molten pool depth, the welding current, molten pool width, molten pool depth, groove width and groove cross-section area are selected as net input parameters, and the molten pool depth is the net output value.

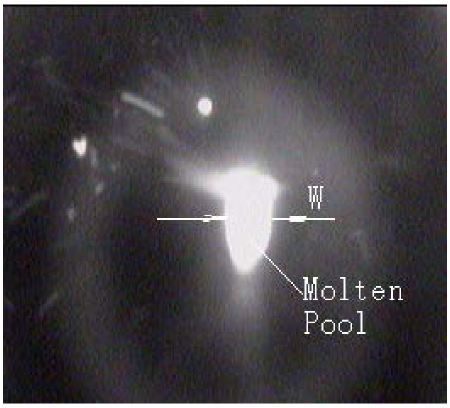
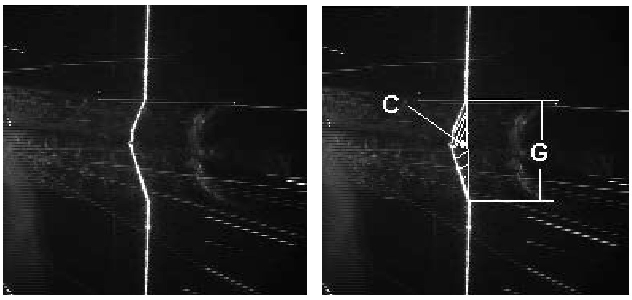


Fig.1 GMAW Molten pool

The groove width and groove cross-section area can be gotten by single stripe laser system [4]. Fig.2(a) is the image gotten by laser shooting to a plate workpiece. As shown in Fig.2(b), G is groove width, and C is groove cross-section area.



(a) (b)

Fig.2 Laser groove images

It must be mentioned that the molten pool has thermal inertia; when the welding current, and groove change, the molten pool has a delayed response. Therefore, the fore information should be considered in the molten pool depth dynamic model. The actual current input parameters of neural network model are present welding current I(t) and the fore three current I(t-1), I(t-2), I(t-3). The same with current, the molten pool width input parameters are W(t), W(t-1), W(t-2), W(t-3), the molten pool area input parameters are S(t), S(t-1), S(t-2), S(t-3). As the arc light around the torch is very strong, the laser should be shoot to the groove position about 20mm before the welding torch for avoiding the arc disturbance. Therefore, current groove parameters must be stored into the memory of controller beforehand. The groove width input parameters are G(t’), G(t’-1), G(t’-2), G(t’-3), and the groove cross-section input parameters are C(t’), C(t’-1), C(t’-2), C(t’-3). Fig.3 illustrates a three-layer Back Propagation (BP) Neural Network Model which is used to predict GMAW pool depth.

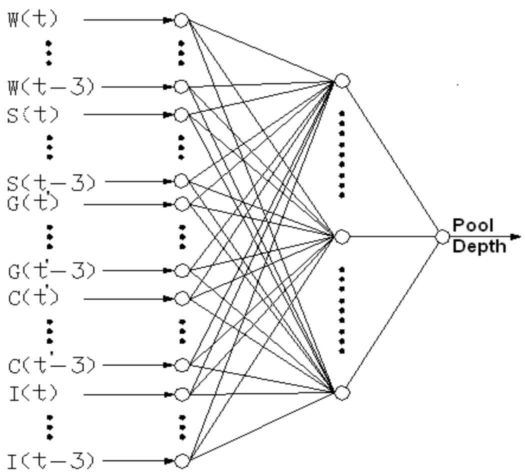


Fig.3 BP Neural Network model

The neural network is trained by using back propagation method. The learning rate and the momentum term are 0.5 and 0.9 respectively. The training samples should be made to cover the whole sample space so that the neural model has good capability of generalization. Welding current, groove width and groove cross-section are selected as independent input parameters. The welding current is chosen from 180A to 280A, the groove width is chosen from 0 mm to 12 mm, and the groove area is chosen from 0 mm^2 to 4 mm^2. As for the hidden-layer units number, the 15-30 range is determined according to experience, then these networks with different hidden-layer units are trained respectively, and the training errors are compared. The network minimal error is below 3.8% after training enough times, and the resultant number of the units in the hidden layer is 20. It should be mentioned that plenty of data is needed for network training, numerical simulation method can be used for data acquiring [5].

Compared with other modeling methods, neural network model have better performance. Undoubtedly, neural network model is much simpler than most other models, and it can calculate the output value quickly.

Controlling system design and experimental results

Experiment hardware system. As shown in Fig.4, the experiment hardware system is made up of robot, laser device, welding machine, wire feeder, MCU, image card, computer, etc.

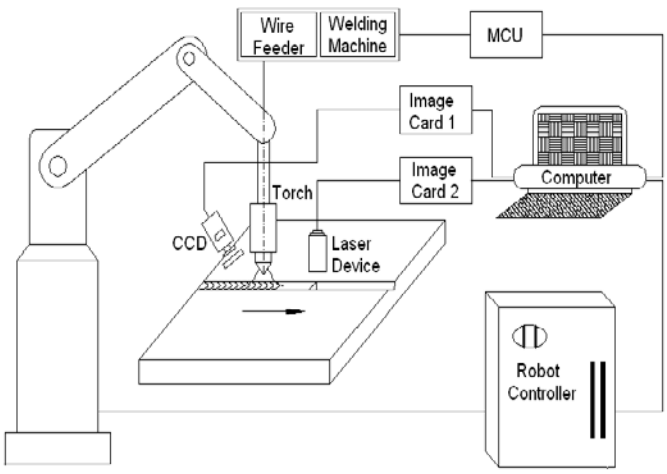


Fig.4 Hardware system

In Fig.4, the laser device is made up of laser emitting equipment, CCD camera and filtering system which matches to the laser wavelength. The CCD camera which is used for getting molten pool image is placed after the torch. In order to eliminating disturbance of arc and spatters, composite filtering system is used for getting well quality molten pool image. The MCU system is used for welding current control, the actual control parameters are delivered from computer to MCU through serial port. The robot moves straight to make welding accomplished.

Fuzzy control system. As shown in Fig.5, the fuzzy controller with two input parameters and one output parameter is used for molten pool control [6]. D is the anticipant molten pool depth, and D_f is the depth calculated by neural network, e is the error between D and D_f, $\dot{e}$ is the variation of e. The output variable u is welding current, it can be inferred by the change of e and $\dot{e}$. e and $\dot{e}$ are divided into 7 grading variables{NB(Negative Big), NM(Negative Medium), NS(Negative Small), Z(Zero), PM(Positive Big)}. Therefore, $\underset{\sim}{E}$ and $\underset{\sim}{CE}$ are gotten. $\underset{\sim}{U}$ is the output of fuzzy decider. $\underset{\sim}{U}$ is also divided into 7 grading variables. Variable u is gotten by quantizing $\underset{\sim}{U}$. The output variable u is quantized in fuzzy domain[-6, +6], total 13 grades, that is {-6,-5,-4, -3,-2,-1,0,1,2,3,4,5,6}.

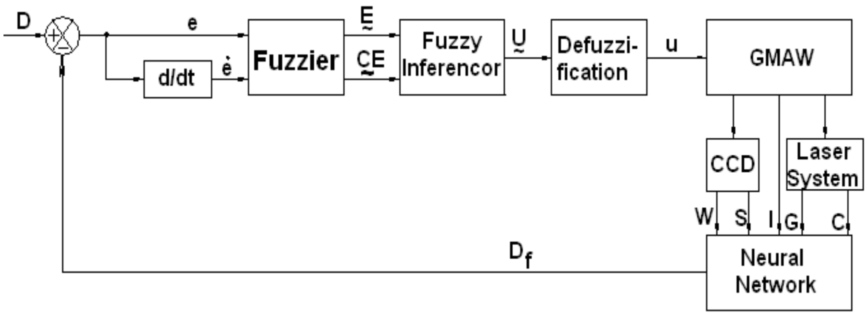


Fig.5 Control scheme of the pool depth

In this paper, membership function adopts triangle-shape function [6]. By experiment of molten pool control, typical control regulations are:

If $\underset{\sim}{E}$ = NB, then $\underset{\sim}{U}$ =PB

If $\underset{\sim}{E}$ = NS and $\underset{\sim}{CE}$ = Z then $\underset{\sim}{U}$ = PS

After plenty of experiment analysis, the total molten pool depth control rules can be gotten as table 1.

Table 1 Fuzzy control rules

$\underset{\sim}{U}$		$\underset{\sim}{E}$						
		NB	NM	NS	Z	PS	PM	PB
$\underset{\sim}{CE}$	NB	PB	PB	PB	PM	PS	NS	NB
	NM	PB	PB	PM	PM	PS	Z	NB
	NS	PB	PM	PM	PS	Z	NS	NB
	Z	PB	PM	PS	Z	NS	NM	NB
	PS	PB	PS	Z	NS	NM	NM	NB
	PM	PB	Z	NS	NM	NM	NB	NB
	PB	PB	PS	NS	NM	NM	NB	NB

Experiment condition and result. The welding conditions are shown in table 2.

Table 2 Welding condition

Workpiece material	Workpiece thickness(mm)	Welding Voltage(V)
Q235	10	24
Welding current(A)	Groove width (mm)	Groove cross-section Area(mm^2)
180~220	0~12	0~4

Fig.6 shows the welding result. It can be obviously seen that the weld pool depth is about constant. The welding current changes with the fluctuation of the groove width and groove cross-section area. The welding current increases when the width of the groove and the area of groove cross-section both become small; the welding current decreases when the width of the groove and the area of groove cross-section both become big; the welding current varies little when the groove width changes but the groove cross-section area keeps unchanged. The experiment results show that the proposed method for controlling the weld pool depth have superior performance.

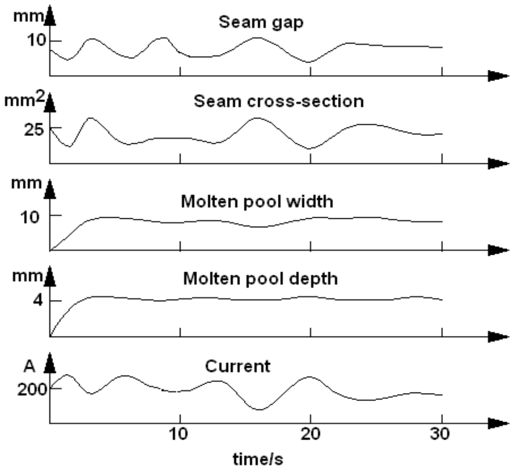


Fig.6 Experiment results

Conclusions

In this paper, the neural network model and control for the GMAW molten pool depth have been investigated. The molten pool depth is predicted by using the information obtained from the welding pool and groove, and fuzzy control method can be used to keep molten pool depth stable. Experiment results demonstrate that the proposed neural network model can predict the molten pool depth accurately, and the proposed fuzzy control method is suitable for GMAW procedure.

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