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铝合金脉冲 MIG 焊焊丝伸出长度视觉检测控制

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摘 要: 针对铝合金脉冲 MIG 焊过程焊丝伸出长度的视觉控制进行了研究. 设计了基于视觉传感的焊丝伸出长度模糊 PID 闭环控制系统，采用基于 xPC 的实时目标环境，建立了铝合金脉冲 MIG 焊快速原型的控制平台，并进行了铝合金脉冲 MIG 焊焊丝伸出长度视觉控制试验. 结果表明，在铝合金脉冲 MIG 焊过程中，视觉传感的方法能够满足焊丝伸出长度稳定性的控制，且利用模糊 PID 控制器建立的快速原型视觉传感控制系统可以实现铝合金脉冲 MIG 焊丝伸出长度的良好控制，具有较强的鲁棒性和快速响应能力.

关键词: 焊丝伸出长度控制; 视觉传感; 模糊 PID; 脉冲 MIG 焊

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0 序 言

在熔化极气体保护焊过程中，弧长和熔滴过渡稳定是保证焊接质量的关键. 许多研究表明，焊丝伸出长度的变化对弧长和熔滴过渡方式都有着显著的影响[1-3]. 针对这个问题，一些学者做了相关的研究. Orszagh 等人[4]通过检测 GMAW 过程焊丝伸出长度变化时电阻变化来实现焊丝伸出长度传感; 鲍云杰等人[5]利用 CO_2 气体保护焊短路中期，焊接脉冲电流恒定，焊炬与工件的电压信号与焊丝伸出长度成正比的关系，实现弧长稳定控制. 马跃洲等人[6]利用电弧声信号结合 SVM 初步实现焊丝伸出长度变化的模式识别.

文中在实现焊丝伸出长度视觉传感的基础上，设计了铝合金 MIG 焊快速原型控制系统，针对单一的 PID 控制器的不足设计了模糊 PID 控制器，并进行了铝合金脉冲 MIG 焊焊丝伸出长度控制试验，获得了稳定的焊接过程，且控制系统具有很好的响应速度与鲁棒性.

1 试验系统组成

试验系统如图 1 所示. 建立的铝合金脉冲 MIG 焊硬件平台主要包括焊接系统、图像传感系统、电信号采集及控制信号输出系统. 焊接系统采用德国 DALEX VIRO MIG-400L 数字脉冲焊机. 图像采集系统包括松下 CP-230 型 CCD 摄像机，NI PCI-1405 视频采集卡. 电信号采集及控制信号输出系统主要有支持 xPC 的研华 PCL-812PG 数据采集卡，NI PCI-6221 数据采集卡，研华 PCL-728 带隔离的 D/A 数据输出卡，辅有 CSM400FA 系列的闭环电流传感器，研华 ADAM-3014 标准电压隔离模块等. 软件平台采用的是支持 xPC 的实时目标环境.

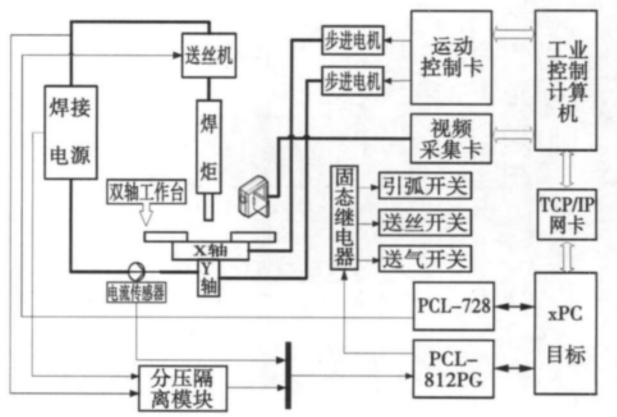

图 1 铝合金脉冲 MIG 焊快速原型控制系统示意图
Fig. 1 Schematic diagram of rapid prototyping control system for aluminum pulsed MIG welding

控制系统采用快速控制原型技术(rapid controller prototyping，RCP)，它能够以方块图表示整个控

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制系统的控制算法，并直接把方块图转化成可执行代码，自动下载到控制电脑上执行，还可以对整个控制系统进行多次、实时在线试验来验证控制系统软硬件方案的可行性[7].

焊接过程中，CCD 摄像机始终保持和焊枪的相对位置不变，焊接过程是采用焊枪固定，工作台行走的自动焊接方式.

2 焊丝伸出长度信号提取

视觉传感系统由 LabVIEW 开发. 视觉传感系统所获得的焊接区图像，如图 2 所示，图像中焊炬口到焊丝端头为可见的焊丝伸出长度. 通过视觉传感系统采集得到的视觉图像，需要经过一定的图像处理算法进行处理，得到焊丝伸出长度的信号，才能将其作为反馈信号输入控制系统中. 焊丝伸出长度的处理算法采用本课题组已有的研究成果，图像处理算法流程如图 3 所示.

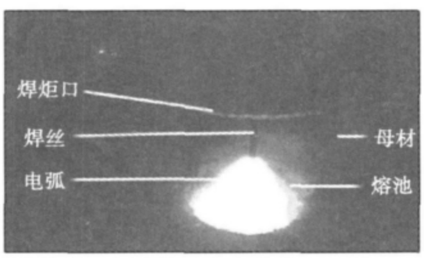

图 2 CCD 获取的图像

Fig. 2 Typical image captured by CCD camera

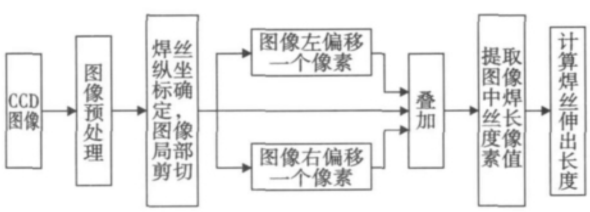

图 3 焊丝伸出长度提取流程

Fig. 3 Detection process of wire extension

3 模糊 PID 控制器的设计

3.1 模糊 PID 理论

模糊 PID 主要思想是基于 PID 控制，结合采用模糊推理的方法实现 PID 参数的在线自调整，使系统动态过程各阶段的 PID 参数处于最佳状态，以获得满意的控制效果. 参数自调整模糊控制的思想是找到 PID 控制器的三个参数 K_p，K_i，K_d 与 e，e_c 之间的模糊关系. 在运行中通过不断检测模糊输入量 e 和 e_c，再根据模糊控制规则对三个输出参数进行在线修改，以满足不同 e 和 e_c 对控制参数的不同要求，从而使被控对象具有良好的动静态性能[8]. 基于视觉反馈焊丝伸出长度的模糊 PID 控制器结构如图 4 所示.

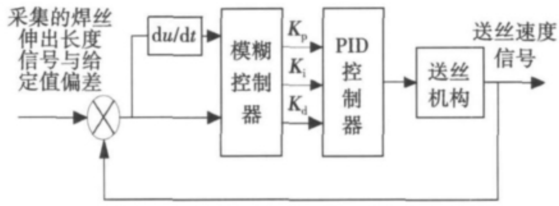

图 4 基于视觉反馈焊丝伸出长度的模糊 PID 控制器结构

Fig. 4 Structure of fuzzy PID controller

3.2 模糊规则的建立

系统采用双输入三输出的模糊控制器，利用偏差 e 及偏差变化 e_c 作为模糊控制器的语言输入变量. 把它的变化定义为模糊集上的论域(NB，NM，NS，ZO，PS，PM，PB)，子集中元素分别代表负大(NB)、负中(NM)、负小(NS)、零(ZO)、正小(PS)、正中(PM)、正大(PB).

e 的论域为 $e=[-3,-2,-1,0,1,2,3]$

e_c 的论域为 $e_c=[-3,-2,-1,0,1,2,3]$

$\Delta K_p \in [-0.3\ 0.3]$，$\Delta K_i \in [-0.06\ 0.06]$，$\Delta K_d \in [-0.03\ 0.03]$

制定的模糊控制规则见表 1，表 2，表 3.

表 1 K_p 的模糊控制规则表

Table 1 Fuzzy control rule table for K_p

K_p	NP	NM	NS	ZO	PS	PM	PB
NB	PB	PB	PM	PM	PS	ZO	ZO
NM	PB	PB	PM	PS	PS	ZO	NS
NS	PM	PM	PM	PS	ZO	NS	NS
ZO	PM	PM	PS	ZO	NS	NM	NM
PS	PS	PS	ZO	NS	NS	NM	NM
PM	PS	ZO	NS	NM	NM	NM	NB
PB	ZO	ZO	NM	NM	NM	NB	NB

表 2 K_i 的模糊控制规则表

Table 2 Fuzzy control rule table for K_i

K_i	NB	NM	NS	ZO	PS	PM	PB
NB	NB	NB	NM	NM	NS	ZO	ZO
NM	NB	NB	NM	NS	NS	ZO	ZO
NS	NB	NM	NS	NS	ZO	PS	PS
ZO	NM	NM	NS	ZO	PS	PM	PM
PS	NM	NS	ZO	PS	PS	PM	PB
PM	ZO	ZO	PS	PS	PM	PB	PB
PB	ZO	ZO	PS	PM	PM	PB	PB

表 3　K_d 的模糊控制规则表

Table 3　Fuzzy control rule table for K_d

K_d	NB	NM	NS	ZO	PS	PM	PB
NB	PS	NS	NB	NB	NS	NM	PS
NM	PS	NS	NB	NM	NM	NS	ZO
NS	ZO	NS	NM	NM	NS	NS	ZO
ZO	ZO	NS	NS	NS	NS	NS	ZO
PS	ZO	ZO	ZO	ZO	ZO	ZO	ZO
PM	PB	NS	PS	PS	PS	PS	PB
PB	PB	PM	PM	PM	PS	PS	PB

ΔK_p，ΔK_i，ΔK_d 的模糊控制规则表建立好后，利用模糊控制规则在线对 PID 参数进行自适应校正.

设 e，e_c，ΔK_p，ΔK_i，ΔK_d 均服从正态分布，因此可得出各模糊子集的隶属度，根据各模糊子集的隶属度赋值表和各参数模糊控制模型，应用模糊合成推理设计 PID 参数的模糊矩阵表，查出修正参数代入式(1)为

$$\left.\begin{aligned} K_p &= K'_p + \Delta K_p \\ K_i &= K'_i + \Delta K_i \\ K_d &= K'_d + \Delta K_d \end{aligned}\right\} \tag{1}$$

4　控制试验及分析

为了检验在铝合金脉冲 MIG 焊过程中，通过视觉检测方法，利用模糊 PID 控制器对焊丝伸出长度的控制效果，在设计的铝合金脉冲 MIG 焊快速原型控制平台的基础上进行了焊丝伸出长度控制试验. 由于送丝速度直接决定着焊丝的进给量，时滞较小，因此系统选用送丝速度作为铝合金脉冲 MIG 焊焊丝伸出长度控制的控制量.

母材牌号为铝合金 50581-H321，其规格为 300 mm × 100 mm × 6 mm; 焊丝牌号为 5356 的铝镁焊丝，其直径为 1.2 mm; 保护气为氩气 25 L/min. 焊接速度为 15 cm/min，脉冲基值电流为 25 A，脉冲峰值电流为 200 A，脉冲频率为 40 Hz，脉冲占空比为 50%.

图 5 为 MATLAB/Simulink 开发的基于焊丝伸出长度视觉检测的模糊 PID 控制程序，将视觉传感系统采集处理后得到的焊丝伸出长度信号通过数据采集卡PCI-6221的模拟输出，输入到控制系统，然后进行控制试验. 图 6 为试验完成后得到的焊缝形貌; 图 7 为焊接过程中典型信号，包括焊接过程中的电流电压信号，图 7c 所控制送丝速度的变化，图 7d 为通过系统的视觉检测所获得铝合金脉冲 MIG 焊过程焊丝伸出长度变化情况. 从图 7c 看出送丝速度在模糊 PID 控制作用下实时变化，而焊丝伸出长度波动范围较小，获得了很稳定的铝合金脉冲 MIG 焊过程.

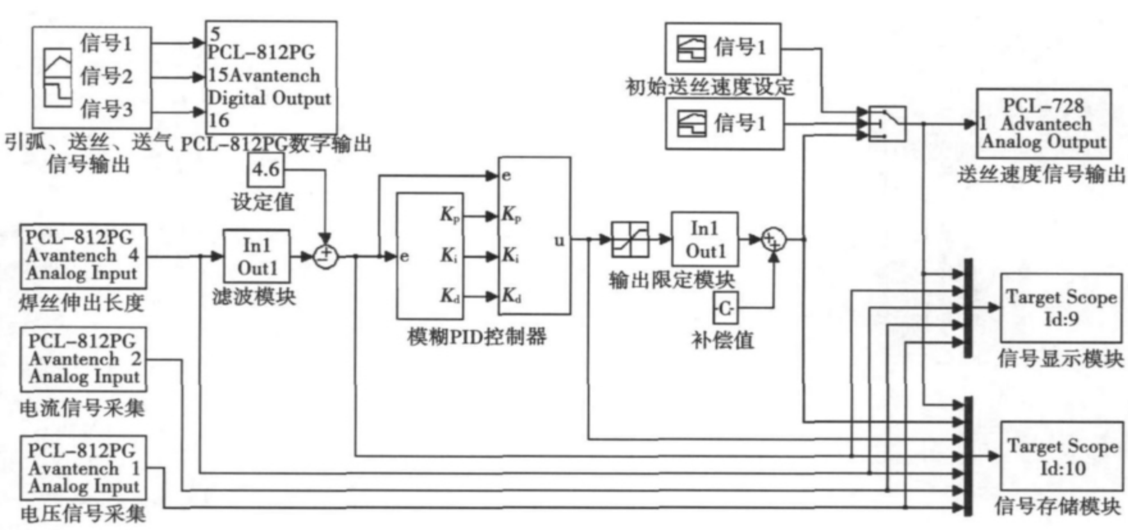

图 5　基于焊丝伸出长度视觉检测的模糊 PID 控制程序

Fig. 5　Fuzzy PID control program for wire extension based on vision sensing

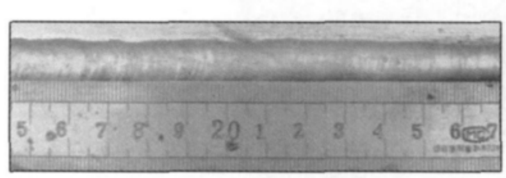

图 6　焊缝形貌

Fig. 6　Welding appearance

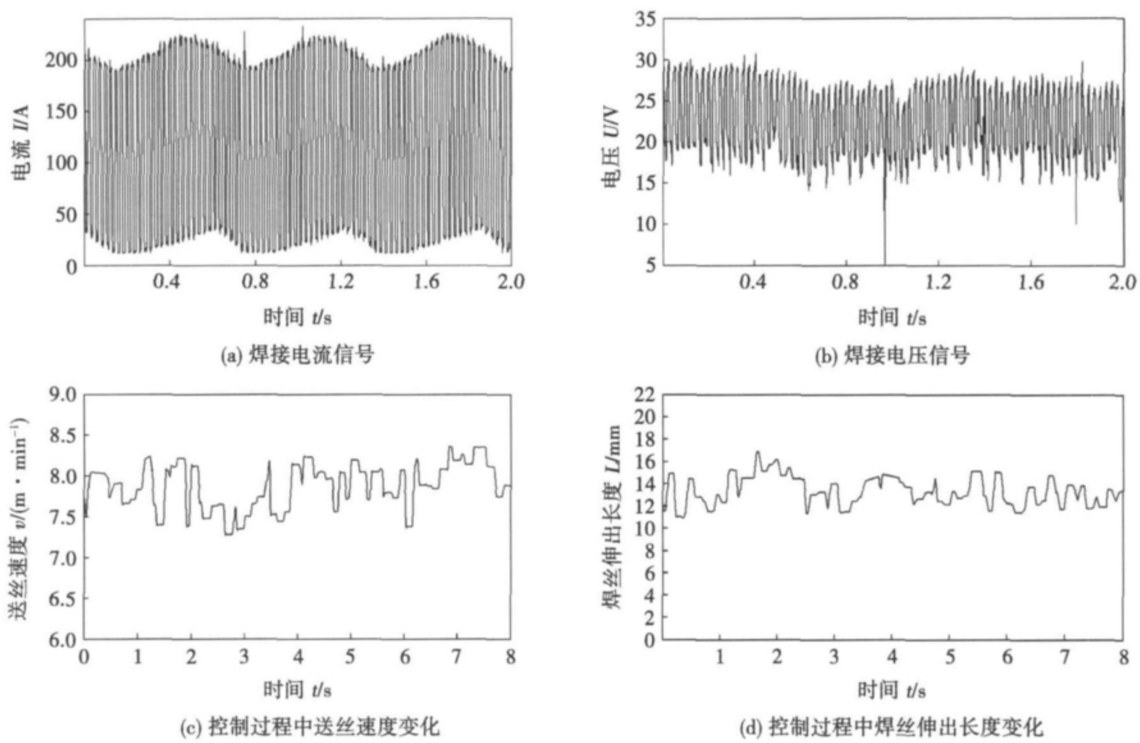

图7 控制过程中典型焊接信号

Fig. 7 Typical welding signals in control process

5 结 论

(1) 利用图像视觉传感和相应的图像处理算法,采用基于 xPC 的实时目标环境,建立了铝合金脉冲 MIG 焊快速原型的视觉传感控制平台.

(2) 利用模糊 PID 控制器建立的快速原型视觉传感控制系统实现了铝合金脉冲 MIG 焊丝伸出长度的良好控制,具有较强的鲁棒性和快速响应能力.

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-58

Abstract: In this paper, Ni60 alloy powders were used to improve the fatigue strength of cruciform joints of Q235B through modification of spray fusing. Test results showed that the section shape of welded joints can be improved by flame spraying. High cycle fatigue test results showed that 2×10^6 cycles offset fatigue strength of the welded joints spray fused by Ni60 increased by 64.5%. The thermal stress was simulated by the finite element (ANSYS12.0) based on spraying parameters. Simulation results show that, the residual stress of substrate material and coating layer is still tensile stress and compared with as-welded joints, the magnitude of tensile stress decreases slightly. The residual stress of as-welded and coating surface is about 238 MPa and 182 MPa respectively. Thus, the residual stress is decreased by 24% after spray fusing.

Key words: modification of pray fusing; fatigue strength; stress concentration factor; residual stress

Microstructure and mechanical properties of magnesium alloy AZ31B solder joint using Zn-Mg filler metal MA Li[1], LONG Weimin[1], QIAO Peixin[1], HE Dingyong[2], LI Xiaoyan[2] (1. State Key Laboratory of Advanced Brazing Filler Metals and Technology (Preparation), Zhengzhou Research Institute of Mechanical Engineering, Zhengzhou 450001, China; 2. School of Materials Science and Engineering, Beijing University of Technology, Beijing 100124, China). p 59-62

Abstract: In order to join wrought magnesium alloy AZ31B sheet high-frequency induction soldering of wrought magnesium alloy AZ31B using Zn-Mg filler metal was investigated. The microstructure of the Zn-Mg filler metal was evaluated. Both the interface microstructure and the mechanical properties of the solder joint were studied. The interface microstructure and formation phases of the soldering seam were investigated by X-ray diffractometer, scanning electron microscopy and X-ray energy dispersive spectrometer. The strength of the solder joint and the microhardness of the interface microstructure were tested. The results show that Zn-Mg filler metal reacts with the base metal AZ31B, and α-Mg matrix and α-Mg + γ-MgZn eutectoid structure are formed in soldering seam, and the microstructure in the original Zn-Mg filler metal disappearing after the soldering process. The average tensile strength of the butt joint is 51 MPa and the average shear strength of the overlap joint is 36 MPa. The microhardness of the α-Mg + γ-MgZn eutectoid structure is the maximum in the solder joint. The fracture morphology of the solder joint exhibits intergranular fracture mode and the fracture comes from α-Mg + γ-MgZn eutectoid structure.

Key words: AZ31B; Zn-Mg filler metal; induction soldering; eutectoid structure; joint strength

Vision sensing and control for wire extension in pulsed MIG welding of aluminum alloy LU Lihui[1], SHI Yu[2], HUANG Jiankang[1], FAN Jiawei[1], FAN Ding[2] (1. Key Laboratory of Non-ferrous Metal Alloys and Processing. The Ministry of Education, Lanzhou University of Technology, Lanzhou 730050, China; 2. State Key Laboratory of Gansu Advanced Non-ferrous Metal Materials, Lanzhou University of Technology, Lanzhou 730050, China). p 63-66

Abstract: Research work of wire extension control based on vision sensing was done in pulsed MIG welding process of aluminum alloy. A rapid prototyping control platform was established for pulsed MIG welding of aluminum alloy using real-time target environment based on xPC. With vision sensing of welding zone image and corresponding image processing algorithm, a fuzzy PID closed loop control system for wire extension was designed on the basis of the built rapid prototyping control platform. Then experimental results show that the method of vision sensing can meet the control requirements of wire extension stability, the rapid prototyping control system built with fuzzy PID controller based on vision sensing can realize the well control of the wire extension in pulsed MIG welding of aluminum alloy and also has strong robustness and quick response ability.

Key words: extension control; vision sensing; fuzzy PID; pulse MIG welding

Stress corrosion behavior of diffusion bonding joints of 316L stainless steel in environment of acid NaCl solution HUANG Yuhui, YANG Bo, XUAN Fuzhen, TU Shandong (Key Laboratory of Pressure Systems and Safety, MOE, School of Mechanical and Power Engineering, East China University of Science and Technology, Shanghai 200237, China). p 67-70

Abstract: Because of special diffusion bonding process, solution quenching was carried out to reduce the possibility of sensitization. Slow strain rate test (SSRT) was adopted in order to assess stress corrosion cracking (SCC) behavior of diffusion bonding joints of 316L stainless steel in the environment of acid NaCl solution with different HCl concentration at the temperature of 80 ℃. Microhardness distribution was measured, and the relationship between mechanical properties and stress corrosion resistance properties was also discussed in this study. Test result showed that stress corrosion cracking initiated at diffusion bonding joint, solution quenching after welding could improve stress corrosion cracking resistance properties in specific environment.

Key words: 316L; diffusion bonding joints; slow strain rate test; stress corrosion cracking; solution quenching

Digital control TIG welding system with high frequency pulse assembled and process properties YAN Sibo[1], SONG Yonglun[1], ZHANG Wanchun[2], LUO Chuanguang[2] (1. College of Mechanical Engineering & Applied Electrons Technology, Beijing University of Technology, Beijing 100124, China; 2. Changzheng Machinery Company, China Aerospace Science and Technology Corporation, Wanyuan 636371, China). p 71-74

Abstract: The high frequency current pulse(≥20 kHz) output is difficult to achieve because of dynamic characteristic limit. The digital control TIG welding system with high frequency pulse assembled has been proposed in this research. This system adopts novel power circuit with DSP and CPLD control. By which the system can achieve high frequency pulse welding according to special scheduling and external characteristic control. This stable welding processing can decrease the number of blowholes during