

超高频脉冲 TIG 焊电弧形态分析

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摘 要:设计出了一一种新的高速摄像拍摄技术,可以拍摄脉冲焊中任意时刻电流对应的电弧. 利用脉冲焊中电流周期性变化的规律,在不同脉冲电流周期的相同点拍摄几十张照片并取其直径的平均数,解决了一般性能的高速摄像机拍摄速度低于超高频脉冲电流变化速率的问题. 基于自主研制的高频 TIG 焊接设备进行了工艺焊接试验,并利用 MATLAB 技术处理图像,研究了基值电流 I_b 为 50 A,峰值电流 I_p 为 100 A 的焊接电弧. 结果表明,电弧随脉冲变化时间常数为几十微秒. 在脉冲电流突变时,对脉冲电弧加热及散热进行了分析,发现电弧扩张速度大于收缩速度.

关键词:脉冲焊; 高速摄像; 电弧变化; 时间常数

中图分类号: TG 403 **文献标识码:** A **doi:**10. 12073/j. hjxb. 2018390035

0 序 言

电弧研究对于焊接质量的提高具有重要的意义,国内电弧物理的研究十分薄弱,与 21 世纪焊接技术的发展水平很不相称^[1]. 由于焊接过程中电弧发出强烈的光和热,给熔池和电极的观察带来了相当大的困难. 采用通常方式的观察或摄像,往往只能看到等离子体电弧的强烈光亮,而无法看清被等离子体电弧所包围的电极变化以及处在等离子体电弧下面的焊接工件表面熔池的流动情况^[2]. 高速摄像技术是一种先进的测试手段,它能把一个高速的运动过程或者高速瞬变过程的空间信息和时间信息联系在一起^[3]. 结合滤光镜技术,高速摄像机可以清晰的拍到电弧形态^[4-5]. 因此越来越多的学者用高速摄像来研究电弧物理,但是鲜有论文对高频焊接过程中高速摄像机拍摄技术进行研究.

高频脉冲焊是现在众多学者研究的热点,研究表明,矩形波脉冲电流的高频压缩效应最为显著^[6]. 北京航空航天大学研究团队自主研发了快变换超音频直流脉冲 TIG 焊设备,通过改变脉冲电流频率、电流峰值、基值、占空比等焊接参数,研究电弧电学特性、电弧力、电弧形态及稳定性等,发现高频脉冲焊各方面均优于常规直流 TIG 焊^[7-9]. 随着高性能晶体管的出现,高频脉冲焊中电流变化频率可达 80 kHz,而一般性能的高速摄像机拍摄速度很难达到每

秒 8 万张. 脉冲焊中电流是周期性变化的,高速摄像机每秒拍摄的几千甚至上万张照片并不容易与脉冲电流值相对应. 高速摄像拍摄技术的不成熟给脉冲焊的电弧研究造成极大的阻碍. 亟须一种拍摄技术去解决以上两个问题,以便更好的研究脉冲焊接中的电弧形态变化. 探讨一种新的高速摄像拍摄脉冲焊电弧的方法,这种方法既可以使拍摄的众多照片和脉冲电流值一一对应,又可以解决一般性能的高速摄像机拍摄速度小于超高频脉冲电流频率的问题.

1 高速摄像系统

应用高速摄像机拍摄焊接电弧需要一套完整的拍摄系统. 由于强烈的弧光干扰,在高速摄像机拍摄电弧时需要专用的背光灯光源和滤光片. 除此之外,还需要与计算机连接的存储装置和三角架等. 文中使用的高速摄像机是美国 IDT 公司生产的 Y4 系列的 Y4-S1 型,其摄像的最大分辨率为 1024 × 1024 点阵. 拍摄前在装有其专用的软件的计算机屏幕上相关设置,主要设置曝光时间、拍摄张数、触发模式和图片大小等. 外部触发模式下摄像机的最小曝光时间为 5 μs,设置外部触发脉冲高电平时间为 4 μs. Y4-S1 自带存储装置,实际使用时只需用网线把存储装置和任意电脑联接在一起,并更改电脑 IP 地址,拍摄后就可以在电脑上直接读取图片或选择性储存. 探讨的高速摄像机拍摄技术,在原系统基础上增加一个外部触发装置. 单片机输出的脉

冲,通过触发装置的硬件电路可以直接驱动摄像机进行拍摄。

2 软件和硬件电路

高频脉冲焊是通过开关管的交替导通来切换电流产生方波电流进行焊接的一种焊接方式。北京工业大学自主设计的高频脉冲 TIG 焊机电流波形示意图如图 1 所示。其中基值电流为 I_b ,峰值电流为 I_p 。在脉冲焊机中,核心板中单片机输出脉冲并进行功率放大来驱动 IGBT 导通与关断。高速摄像驱动方案就是基于单片机的脉冲,运用一些算法来输出另一串新的脉冲并进行功率放大后驱动高速摄像。

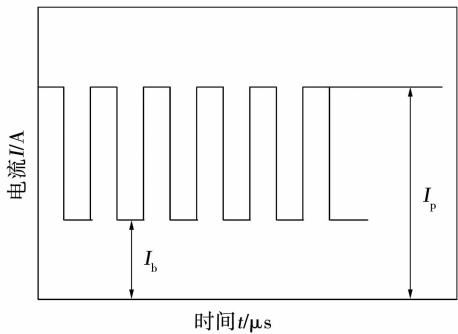


图 1 脉冲焊电流示意图

整体的控制方案是在脉冲的下降沿进入中断,然后通过计时器进行延时,在达到延时的时间产生高电平,高电平维持时间为 $4\ \mu\text{s}$ 。然后间隔数个周期之后再产生一个脉冲,每个脉冲相对于电流下降沿延时时间可自由设定。

由于脉冲频率很高,设计专门的快反应电路对单片机产生的脉冲进行功率放大。同步触发装置具体电路图如图 2 所示。从单片机 dsPIC30F6011A 中出来的脉冲经过 UCC27424 之后,再经过光耦 6N137

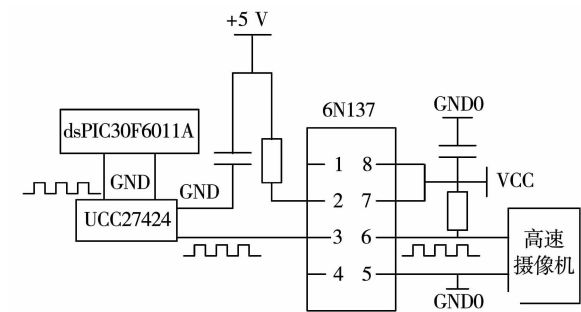


图 2 高速摄像驱动整体框图

Fig. 2 Diagram of drive circuit for high-speed photography

的隔离,驱动高速摄像机。其结构简单,做成的小电路板体积很小。

设定每隔脉冲电流 5 个周期输出一个高速摄像驱动脉冲,每个脉冲持续时间为 $4\ \mu\text{s}$,其实际波形如图 3 所示。其中焊机电流频率为 $20\ \text{kHz}$ 。图 3a 是驱动高速摄像的脉冲在焊机脉冲周期的高电平起始阶段前 $4\ \mu\text{s}$ 。从图 3b 可以看出,每 5 个周期输出一个脉冲,而且脉冲比上一个稍微延后几微秒。

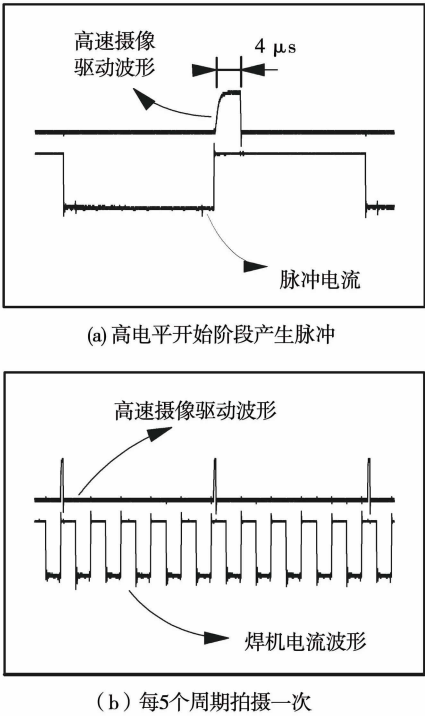


图 3 高速摄像驱动波形

Fig. 3 Waveform of drive circuit for high-speed photography

3 焊接工艺试验

试验选用脉冲电流频率为 5 和 $10\ \text{kHz}$ 两个参数,基值电流 I_b 为 $50\ \text{A}$,脉冲峰值电流 I_p 为 $100\ \text{A}$ 。工件选用 $5\ \text{mm}$ 厚的普通碳素钢 Q235;钨极选用直径为 $3.0\ \text{mm}$ 的钨钨,钨极尖磨成固定角度 70° ;采用直流正接的方式;钨极尖端距离钢板 $5\ \text{mm}$,喷嘴外径 $16\ \text{mm}$,喷嘴内径 $11\ \text{mm}$,喷嘴距钢板距离 $11\ \text{mm}$;保护气用纯氩气,气流量 $15\ \text{L/min}$;行走机构速度为 $0.35\ \text{m/min}$,焊前用角磨机打磨工件去除表面铁锈。

试验参数为 $f=10\ \text{kHz}$, $I_b=50\ \text{A}$, $I_p=100\ \text{A}$ 时,在脉冲周期上选取 20 个定点。 $10\ \text{kHz}$ 频率的脉冲电流周期为 $100\ \mu\text{s}$,每隔 $5\ \mu\text{s}$ 取一个点,脉冲电流上取点示意图如图 4 所示。对称取点有利于统计及

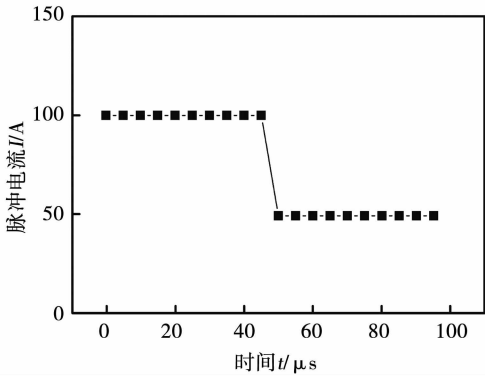


图 4 10 kHz 时脉冲取点位置示意图

Fig. 4 Diagram of point getting position with pulse frequency of 10 kHz

求平均等后期操作. 驱动高速摄像脉冲高电平时间是 $4\text{ }\mu\text{s}$ 左右,试验前将高速摄像机曝光时间设置在 $5\text{ }\mu\text{s}$.

在实际焊接中,对于 10 kHz 频率的脉冲,高速摄像拍 20 张照片为一个拍摄周期. 假设只拍 20 张照片,从摄像机导出照片之后,仍然难以辨认 20 张照片对应的电流值. 设计了一种方案,让脉冲高电平开始的第一个点连续拍 5 张照片,其余点都拍摄一张,这样每个拍摄周期拍摄 24 张照片. 在高速摄像机拍摄之后,做后期统计时,找到 5 张连续的且一致的电弧,就是高电平第一个点.

根据以上取点拍摄方法,一个拍摄周期拍摄的 20 张有效照片如图 5 所示. 电流频率为 10 kHz 时第 1 个取点到第 10 个取点在脉冲电流的高电平,第 11 个取点到第 20 个取点在脉冲电流的低电平. 从拍摄的照片可以看出第 1 张到第 10 张照片电弧直径逐渐增大,第 11 张照片到第 20 张照片电弧直径逐渐减小,与实际情况相符,验证了方法的可行性.

4 电弧变化时间常数

脉冲焊电流变化具有周期性,同样脉冲焊电弧变化也具有周期性. 基于新的高速摄像拍摄技术,对脉冲焊电弧变化时间进行研究. 由于拍摄照片较多,而且人为统计存在误差,故用 MATLAB 软件对拍摄照片进行处理,处理完自动导出电弧直径数据. 此次统计电弧中间区域直径,每个数据点是 30 个相同点电弧直径平均值,统计出 5 和 10 kHz 直径变化趋势如图 6 所示.

由于 5 kHz 时周期较大,电流突变时电弧直径变化较快,因此选点比较密集,每隔 $5\text{ }\mu\text{s}$ 取一个点. 而高电流和低电流后期,电弧变化较慢,为了减少统

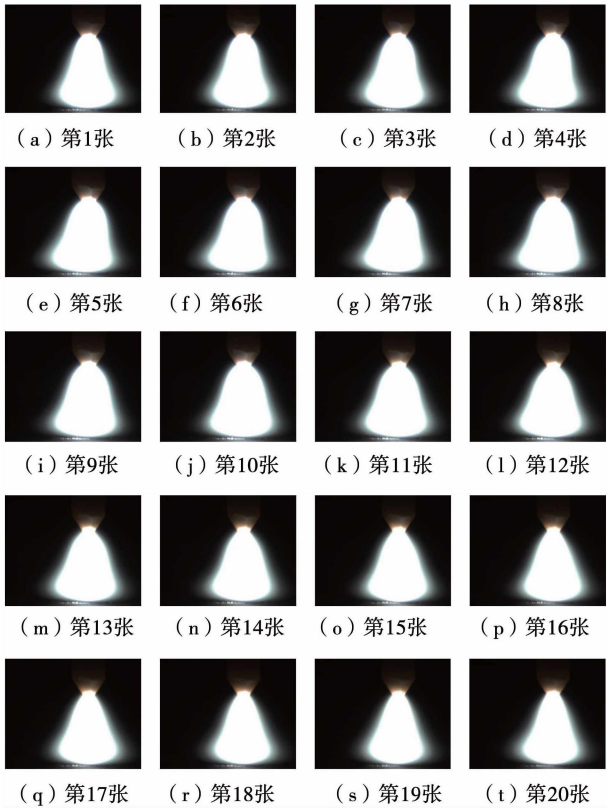


图 5 10 kHz 频率时拍摄的 20 张照片

Fig. 5 20 photos of arc profile with pulse frequency of 10 kHz

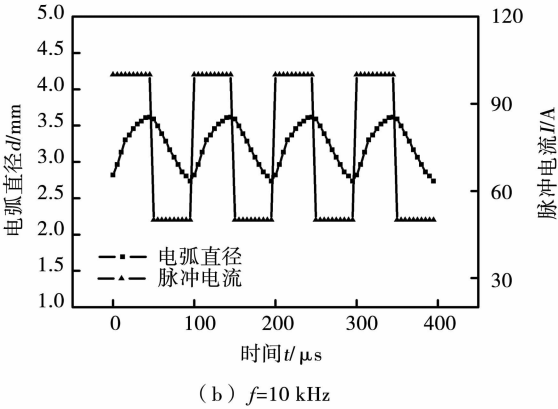
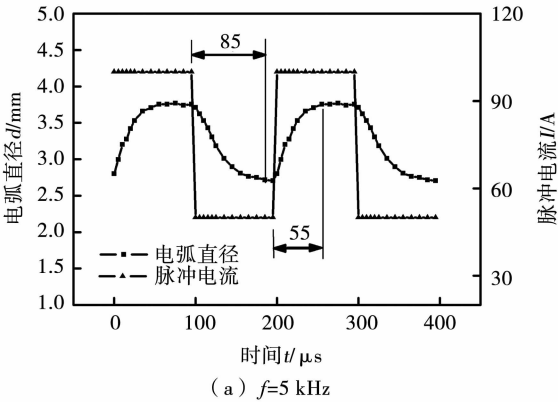


图 6 电弧直径随电流变化趋势

Fig. 6 Changes of arc diameter in different pulse current

计量,每隔 $10\ \mu\text{s}$ 取一个点. $10\ \text{kHz}$ 全部每隔 $5\ \mu\text{s}$ 取一个点. 从图 6a 可以看出,电弧上升时间大约为 $55\ \mu\text{s}$,下降时间大约是 $85\ \mu\text{s}$. 电弧上升速度略大于下降速度. 频率为 $10\ \text{kHz}$ 时,由于电流高电平时间只有 $50\ \mu\text{s}$,电弧直径没有达到稳态就开始随电流下降. 从图 6a,6b 可以看出电弧直径上升速度略大于下降速度. 在 I_b 为 $50\ \text{A}$, I_p 为 $100\ \text{A}$ 参数下,电弧变化时间常数是几十微秒级别. 电弧上升速度比下降速度略快,分析认为在脉冲低电流时,突然给电弧一个大电流,此时焊机热输入量增大,电弧迅速扩张. 当电弧在脉冲高电流时,突然把电流降低一半,此时焊机热输入量大幅减小,电弧能量慢慢消散,消散速度相对较慢,因此下降速度较慢.

5 结 论

(1) 在脉冲焊中,基于电流和电弧周期性变化的特点,用高速摄像拍摄技术对脉冲电流进行定点拍摄,既可以使拍摄的大量照片和脉冲电流值对应起来,又可以解决一般性能的高速摄像机拍摄速度小于超高频脉冲电流变化速率的问题.

(2) 在基值电流 I_b 为 $50\ \text{A}$,峰值电流 I_p 为 $100\ \text{A}$ 的试验条件下,当电流突变时,电弧变化至稳态时间大约是几十微秒,电弧扩张速度比收缩速度略快.

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rameters. Whether the 5E61 aluminum alloy filled with ER5356 or 5E61 filler wire, the microstructures in the weld were fine and homogeneous, but the microstructures in the fusion zone were slightly coarsened compared with the microstructure in the weld. When the ER5356 wire was used as filler wire, metal phases were dissolved fully in the weld zone, and the welded joint strength was reduced. If 5E61 filler wire was used, a portion of Er element was precipitated as the second phase, the size of the phase unit was very close to Al matrix with a small misfit degree, so the mechanical properties of welded joints were improved. The results show that the hardness of welded joints could reach up to 85% of that of the 5E61 aluminum alloy base metal.

Key words: VPPAW; aluminum alloy; mechanical properties; hardness

Interfacial microstructures and mechanical properties of transient liquid phase (TLP) bonding of Ti_2AlNb alloy with Ti/Ni interlayer CAI Xiaoqiang, WANG Ying, YANG Zhenwen, WANG Dongpo (Tianjin Key Lab of Advanced Joining Technology, Tianjin University, Tianjin 300072, China) . pp 24 – 28

Abstract: A reliable Ti_2AlNb alloy joint was successfully obtained by transient liquid phase (TLP) bonding technique with Ti/Ni interlayer. The effects of bonding time on the interfacial microstructures and mechanical properties of the TLP bonded Ti_2AlNb joints were investigated. The results showed that the joint is primarily consisted of two characteristic zones of isothermal solidification zone (ISZ) and thermal solidification zone (ASZ), and the typical interfacial microstructures of the joints are $\text{Ti}_2\text{AlNb/B2/Nb}_3\text{Al} + \text{B2} + \tau_3 + \text{Ti}_2\text{Ni/Ti}_2\text{AlNb}$. With the increase of time, Nb_3Al and Ti_2Ni phases vanish. Additionally, the τ_3 phase in the joint is gradually decreased and B2 phase increases with the increase of time. The maximum shear strength at room temperature reached up to 428 MPa when the joint was bonded at 1 180 °C for 20 min, while it was 407 MPa at 650 °C. The crack primarily propagates at τ_3 phase in ASZ.

Key words: Ti_2AlNb alloy; TLP bonding; interfacial microstructure; high-temperature property; shear strength

Study on arc profile of high frequency TIG welding

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Abstract: A new high-speed photography technology was designed and the arc profile corresponding to any current in pulsed welding can be photographed through this technology. This technique utilizes the law of periodic variation of pulsed welding current. Firstly, dozens of photos at the same moment were taken in different pulse current period and then the average diameter of the arc was calculated. The problem that the speed of general high-speed photography rate is lower than the rate of ultra-high frequency pulse was solved. Based on self-developed high frequency TIG welding equipment, the actual welding experiment was carried out, and the MATLAB technique was used to process images. The base current I_b was set to be 50 A and the peak current I_p was set to be 100 A. Experimental results showed that the time constant of the arc varies with the pulse is tens of microseconds. With the pulse current dropping and rising, the cooling and heating process of pulsed arc were analyzed, the diffusion speed of arc was found to be faster than that of the

arc shrinking speed.

Key words: pulsed welding; high-speed photography; change in arc profile; time constant

Numerical simulation of temperature field and stress-strain field in brazed-fusion butt joint between aluminum alloy and galvanized steel with different thickness by arc-assisted laser

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Abstract: The brazed-fusion welded joint prepared by 5A06 aluminum alloy sheet of 2 mm in thickness and ST04Z steel sheet with 1 mm in thickness was taken as the research object. Based on ANSYS finite element software, the misalign hybrid heat source combined Gaussian heat source model for TIG arc and 3D pyramidal heat source model for laser heat source was founded, and the temperature field and the stress strain distribution in the welding process were obtained by using Coupling Analysis. The results show that the arc used the longitudinal stress in brazed-fusion welded joint of 5A06 aluminum alloy sheet and ST04Z steel sheet with different thickness and its adjacent zone is tensile stress. Large compressive stress and severe deformation occur in the steel side away from the weld seam. Relative small compressive stress and deformation happen in the aluminum side away from the weld seam. Temperature field and residual stress simulation results are in good agreement with the experiment results, which proves that the heat source model is correct.

Key words: aluminum steel; arc-assisted laser; butt welding; fusion-brazing; numerical simulation

Numerical analysis of mass distribution in side shielding gas in laser welding

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Abstract: The plasma, keyhole and molten pool were affected by shielding gas in laser welding. Considering the effect of plasma ejecting from keyhole, a three dimensional composition transport model of side shielding gas, air and plasma was established. The mass fraction of each species was calculated on the surface of workpiece and thickness direction. The effects of the angle, position of side shielding gas tube and flow of shielding gas on weld quality were analyzed. The results demonstrated that the distribution of mass fraction of shielding gas is changed by plasma ejecting from keyhole, the weld seam and heat affected zone cannot be protected if the distance between shielding gas tube and keyhole center is too large, or the angle is too small. In addition, the plasma will be blown off by too large shielding gas. The workpiece can be protected effectively through welding experimental of TC4 titanium alloy, 6061 aluminium alloy and Q235 steel plate.

Key words: laser welding; shielding gas; plasma; keyhole

Defect detection of polyethylene pipe butt-fusion welded joint based on continuous-excitation infrared thermal imaging technology

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Abstract: According to the structure and thermal charac-