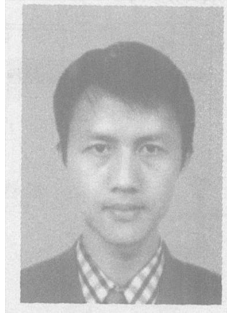
基于焊点压痕的伺服焊枪点焊质量在线检测方法

张小云， 张延松， 陈关龙
（上海交通大学 机械与动力工程学院，上海 200030）


张小云

摘　要：针对目前车身点焊质量检测广泛采用的破坏性检验和无损检测方法中存在离线、小样本、检测成本高的缺点，借助于伺服焊枪编码器的位移反馈特性提出一种基于压痕的焊点质量在线检测方法。试验建立包括机器人及控制器、伺服焊枪和焊接控制器在内的点焊试验系统，利用伺服焊枪编码器位置反馈特性在线获取焊点压痕，通过PLC位移采集系统在线标定压痕获取精度，最后以0.8 mm的普通低碳钢板（GMW2）为例，完成基于压痕的焊点质量在线评价。试验结果证明，伺服焊枪编码器位置反馈精度能够满足焊点压痕测量要求，点焊接头质量在线评价的准确率符合实际生产要求，文中提出的基于压痕的点焊质量在线评价方法可以实现点焊接头的在线检测。

关键词：电阻点焊；伺服焊枪；焊点压痕；在线检测
中图分类号：TG43　　文献标识码：A　　文章编号：0253－360X(2006)10－057－04

0 序　言

电阻点焊（RSW）完成车身90%以上的装配工作量，是车身装配连接最主要的工艺形式。良好的焊点质量不仅有利于轿车的安全性和可靠性，还会影响到轿车车身外观质量以及装配精度。目前广泛采用的焊点质量破坏性检测和无损检测法由于小样本、离线、滞后性等缺点，并不能保证车身所有焊点接头的合格率都保证在规定的范围内。因此，研究焊点质量在线检测方法，在线检测点焊接头质量就显得非常重要。

目前，国内外许多专家学者都在致力于焊点质量在线检测方法的研究，并提出了各种点焊质量在线检测方法[1~4]，通过采集点焊动态电阻、电极压力或电极位移曲线等参数，提取特征信息，与合格焊点相关信息进行对比，来判断焊点好坏。但这些方法由于要外接传感器而受到实际焊接工位和工况的限制，大多只限于试验室研究，难以适应生产线流水作业的要求。文献[5]研究表明，焊点拉剪力与压痕之间存在一定的对应关系，文中针对三种不同的焊接材料，纯钛、1020钢和3003铝合金，通过试验得出当焊点压痕位于工件厚度的5%~10%时，能确保焊点有可靠的拉剪力。

近几年来，Renault，Mazda，Toyota，Honda等国外大型汽车公司已经开始将伺服焊枪应用于车身点焊生产线上，伺服焊枪通过交流伺服电机驱动电极来完成焊接过程。文献[6，7]研究表明，利用电极压力可调节的伺服焊枪进行点焊可以有效地减少焊接过程中的碰撞，延长电极寿命，提高焊点质量。同时，交流伺服电机编码器可以实时反馈电极位移，从而可以在线获取焊点压痕，根据文献[5]所述，伺服焊枪也为焊点质量在线检测提供了可能。

从研究伺服焊枪在点焊质量在线检测中的应用角度出发，首先将Fanuc焊接工业机器人及其控制器、伺服焊枪、焊接控制器进行集成，借助伺服焊枪编码器位置反馈特性在线获取焊点压痕，通过激光位移传感器及其PLC数据采集装置对伺服编码器中获取的压痕进行标定，最后以0.8 mm，GMW2低碳钢为例，验证基于压痕的焊点质量在线检测方法的可行性。

1 伺服焊枪点焊系统集成

伺服焊枪点焊控制系统主要由伺服焊枪、焊接机器人、机器人控制器及焊接控制器四部分组成，它们之间的集成如图1所示。

机器人控制器是整个点焊系统的主控制器，控制整个焊接工序。机器人控制器通过伺服电源和伺服信号电缆与机器人连接，除了驱动机器人的六轴运动以外，其中专门的伺服模块还对伺服焊枪轴，即第七轴进行驱动和控制，以实现焊接过程中电极进给、加压、保压以及焊枪打开等功能，并且机器人控制器可以实时监控伺服编码器的信息，反馈电极当

收稿日期：2005－09－22
基金项目：国家自然科学基金资助项目（50575140）；高校博士点基金资助项目（20050248028）

前所在位置。机器人控制器使用数字量输入输出模块Process I/O 板与焊接控制器连接,进行焊接信号的通讯。焊接控制器则采用专门的焊接电源和温控反馈电缆连接到伺服焊枪焊接变压器中,监控焊接过程中的焊接电流和变压器温度,确保焊接过程安全有效地进行。

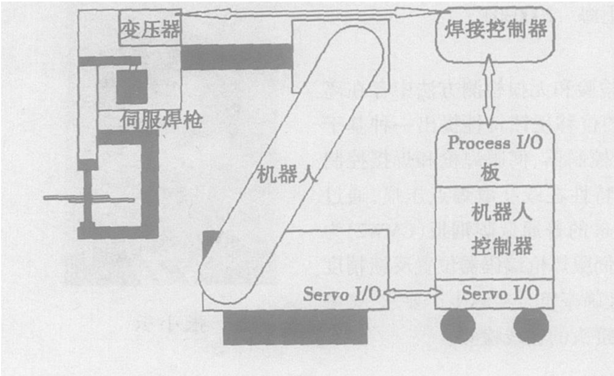


图 1 机器人伺服焊枪点焊系统

Fig. 1 Robot servo gun spot welding system

集成完毕后的伺服焊枪系统,经过 Mastering, Autotune, Pressure Calibration 等调试工序,可以进行正常的加压、发送和接收焊接信号、保压以及打开焊枪等动作,完成点焊过程,获得点焊接头。

2 焊点压痕在线获取

2.1 压痕在线获取方案

通过读取保存伺服焊枪编码器信息的寄存器数据来在线获取焊点压痕。为此,试验中开发用于提取焊点压痕检测的程序,焊接过程中调用该程序可以在线测量焊接前后的工件厚度,其差值即为该焊点压痕。其压痕获取界面如图 2 所示。

```
SERVO GUN / EQ:1 Gun:1                      1/9
  1  Pressure cond number:     (stnd  0)   1
  2  Backup cond number:       (stnd -1)   1
  3  Wear down value(Gun)(mm):            0.01
  4  Wear down value(Robot)(mm):         -0.01
  5  Pressure value(kgf):               300.00
  6  Current position(Gun)(mm):         -28.47
  7  Thickness at last check(mm)
  8    Specified thickness:               1.60
  9    Robot measured thickness:          1.43
```

图 2 焊点压痕在线获取

Fig. 2 On-line welding spot indentation acquisition

黑色方框内的值即为所测得的焊后工件厚度,单位为 mm,测量精度为 0.01 mm。图例中焊前工件厚度为 1.60 mm,焊接完毕后测得的工件厚度为 1.43 mm,其差值为 0.17 mm,该焊点压痕即为170 μm。

2.2 影响压痕在线获取准确性因素分析

焊枪变形和工件变形是导致压痕在线测量误差的主要因素。为了消除焊枪变形导致的测量误差,在使用板厚测量程序时,将板厚测量的电极压力设为 0 N;为了消除工件变形产生的测量误差,在板厚测量过程中,使用控制器自带的 Gun Sag 焊枪浮动功能,来补偿工件受压变形量。

3 焊点压痕在线标定

由于焊枪的伺服电机传动比、传动误差、回程误差、丝钢以及带轮的传动间隙等因素,会导致从伺服编码器中获取的压痕与真实值产生一定的偏差。试验中利用激光位移传感器来对编码器在线获取的压痕进行标定,以获取准确的实际焊点压痕。

3.1 压痕标定系统组成

标定时采用 Omron 非接触式激光位移传感器 Zx—LD30V, PLC 主机 CS1H—CPU65H 及其模拟量 I/O 模块MAD44 及提供焊接开始和结束开关量信号的继电器来在线测量焊点实际压痕,从而标定机器人控制器中所获得的压痕值。

传感器的测量精度为 0.25 μm,动态响应时间为 0.3 ms,最大量程为 4 mm,能够满足点焊压痕在线获取的要求。传感器的安装方案如图 3 所示。激光位移传感器安装在下电极杆,传感器反射板安装在上电极杆,焊接时上电极运动带动反射板上下运动,位移传感器便能够实时反馈出电极位移变化情况。通过模拟量模块采集传感器末端信号线输出的电流信号来获得相应的位移值。

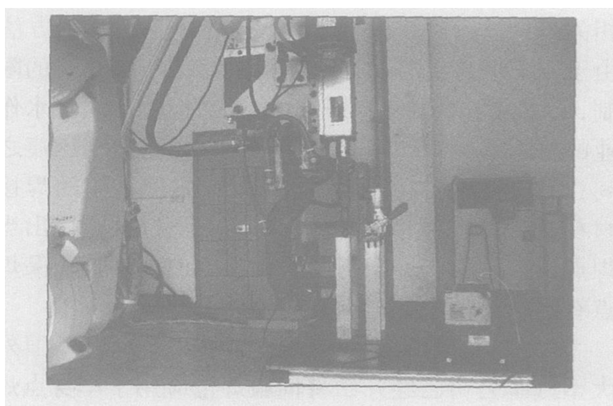


图 3 焊点压痕标定方案

Fig 3 Method for welding spot indentation calibration

焊接过程中采集压痕时，在焊接开始信号和完毕信号的上升沿，记录这两个时刻的位移传感器信号，相减后便能获得焊点的实际压痕。为此，4 路模拟量 I/O 模块中使用 3 路，分别采集焊接开始、焊接完毕信号以及传感器的模拟量信号。编程前对模拟量 I/O 模块进行初始化，将第 1 路和第 2 路输入设定为具有断开检测功能的工作方式，以接收焊接开始和结束的开关量信号，将第 3 路输入设为接收 4 ~20mA 电流输入的工作方式，与传感器的电流输出范围相对应，其 A/D 转换的结果正好对应传感器的实测位移。

初始化完毕，根据如图 4 所示的程序流程图，使用上位机软件 Cx—Programmer 对 PLC 进行梯形图编程。

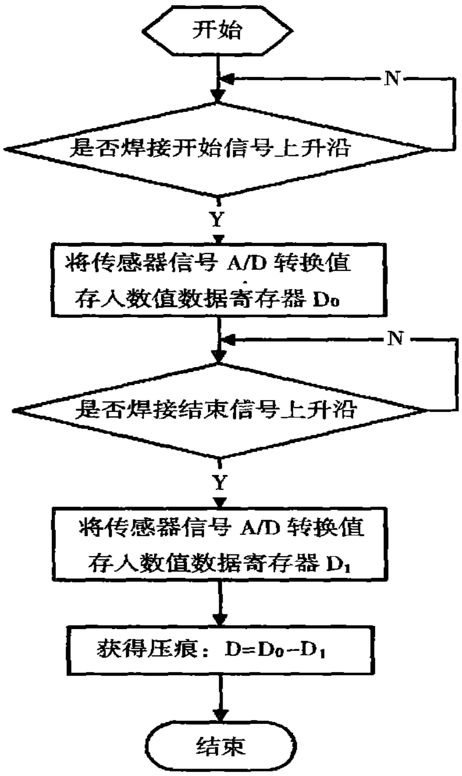


图 4　压痕获取流程图

Fig. 4　Flow chart for indentation acquisition

在焊接开始信号的上升沿记录位移传感器的值，存入数据寄存器 D_0，在焊接完毕信号的上升沿记录位移传感器的值，存入数据寄存器 D_1，同时将二者相减，获得焊点实际压痕 D。

3.2　压痕在线标定结果

以伺服编码器中在线获取的压痕为横坐标，PLC 采集的压痕值为纵坐标，并进行线性插补，结果如图 5 所示。由图中可知，编码器中在线获取的压痕与 PLC 采集的焊点真实压痕基本成线性，比例系数 0.997（接近 1），偏差 63 μm，有超过 95％的焊点压痕偏差在 ±20 μm 以内，在允许的测量误差范围内。因此，将从编码器中获取的焊点压痕值加上 63 μm 即可得到焊点的实际压痕。

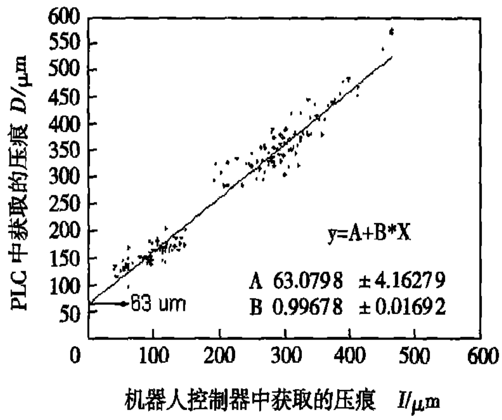


图 5　焊点压痕标定结果

Fig 5　Results of indentation calibration

4　焊点质量在线评价案例

以 0.8 mm，GMW2 低碳钢板为例，采用从伺服编码器中获取的压痕来进行焊点质量在线评价。

4.1　合格焊点压痕范围确定

文献[5] 中虽然指出当焊点压痕介于一定的范围内时能够保证焊点有足够的拉剪力，但是对于具体不同厚度，不同材料的板材，这个范围并不是唯一确定的。因此，采用如下试验方法确定 0.8 mm 普通低碳钢板（GMW2）的合格焊点压痕范围。

首先，使用不同的焊接参数（电流 8 ~12.5 kA，时间 8 ~ 12 周波，电极压力 2.2 kN）进行点焊试验，确定合格焊点的可焊性范围（Weld lobe）。其左边界由拉剪力不小于 3 500N 决定，而右边界由疲劳强度决定。根据美国 GM 公司的现行标准，当焊点压痕达到工件厚度的 20％时，疲劳强度达不到规定要求。由此确定的 2.2kN 下 Weld lobe 如图 6 所示。

然后确定左边界，即等拉剪力线上各点的压痕值。使用左边界上的焊接参数进行焊接试验并测量焊后的压痕，结果如图 7 所示，各点的压痕非常接近，可见可焊性范围左边界等拉剪力线与等压痕线基本重合，取平均值 162 μm 作为合格焊点的压痕下限，而右边界的压痕则为 20％板厚，即 320 μm。

4.2　点焊质量在线评价结果

在 2.2 kN 电极压力，8 ~ 12kA 焊接电流，8 ~ 12 周波焊接时间进行共 21 次点焊试验。从编码器中

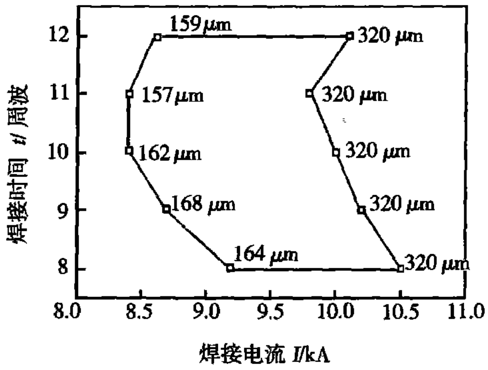


图 6 2.2 kN 下 GMW2 可焊性范围

Fig. 6 Welding lobe for GMW2 under 2.2 kN

在线提取焊点压痕并测量其拉剪力,测得的焊点拉剪力—压痕如图 7 所示。

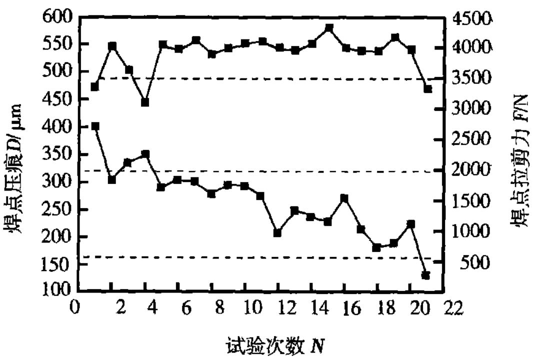


图 7 焊点质量在线评价结果

Fig. 7 Results of on-line welding spot quality inspection

由图 7 可得,根据已确定的合格焊点压痕范围,在所有的 21 组试验中,有 1 点的压痕低于下限,该焊点拉剪力低于标准值 3 500N;有 3 点的压痕高于上限,测量后发现它们均因工件匹配不佳而发生强烈飞溅而导致。这 3 点中有 2 点的拉剪力低于标准值 3 500N,1 点的强度略高于 3 500N,取该点进行疲劳试验,检测结果疲劳寿命为 5.76× 105,低于标准值(106 次),同样为不合格焊点。基于压痕的焊点质量评价结果与实测的焊点质量情况一致。

5 结 论

从机器人控制器中在线获取的焊点压痕非常稳定,经位移传感器标定后能够反映焊点真实压痕的变化情况;同时,基于压痕的点焊质量在线检测的方法正确率较高,并且能够检测出因为工件匹配不佳引起的焊点质量问题,取代目前广泛采用的离线抽样破坏性检测的效果,实现点焊质量在线检测的功能。

参考文献:

[1] Wei Li, Jack Hu S. Jun Ni. On-line Quality estimation in resistance spot welding [J]. Journal of Manufacturing Science and Engineering, Transactions of the ASME, 2000, 122(3): 511—512.

[2] Jou Min. Real time monitoring weld quality of resistance spot welding for the fabrication of sheet metal assemblies [J]. Journal of Materials Processing Technology, 2003, 132(1—3): 102—113.

[3] Rao D L, Chen L G, Ni C Z. Quality estimation of LD10CS aluminum alloy spot welding using artificial neural network [J]. Shanghai Jiaotong Daxue Xuebao, 2003, 37(2): 167—170.

[4] Yongjoon Cho, Rhee S. Quality estimation of resistance spot welding by using pattern recognition with neural networks [J]. IEEE Transactions on Instrumentation and Measurement, 2004, 53(2): 330—334.

[5] BY K.C. Wu. Electrode indentation criterion for resistance spot welding [J]. Welding Research Supplement, 1968, 10: 69—77.

[6] Colin L, Marc G, Tsutomu M. Servo controlled spot we-lding gun [J]. Robot, 1997, 114: 31—34.

[7] 张旭强, 陈关龙, 张延松, 等. 电阻点焊的伺服焊枪技术特性分析[J]. 焊接学报, 2005, 26(6): 60—64.

[8] 林忠钦, 胡 敏. 轿车白车身点焊装配过程有限元分析 [J]. 焊接学报, 2001, 22(1): 36—40.

作者简介:张小云,男,1981 年 5 月出生,博士研究生。主要研究伺服焊枪点焊质量控制及在线检测,发表论文 4 篇。

Email: fenixzxy@sjtu.edu.cn

nautics, Nanjing 210016, China; 2. The 14th Research Insitute, China Eletronics Technology Group Corporation, Nanjing 210013, China). p53—56

Abstract: Wetting times and wetting forces of Sn-Cu-Ni lead-free solder for different temperatures and three kinds of substrates, including Cu, Au/Ni/Cu, and SnBi/Cu, were measured by means of wetting balance method. The effects of soldering temperature on wettability of Sn-Cu-Ni lead-free solder on different substrates were also studied. The results indicate that with the increase of temperature, the surface tension of the lead-free solder decreases, and the wetting times are reduced observably, and the wetting forces are increased evidently. The wettability of solder on Au/Ni/Cu or SnBi/Cu substrate is better than that on Cu substrate owing to the decrease of the interfacial tension between solder and substrate by way of plating Ni/Au or SnBi coating.

Key words: lead-free solder; Sn-Cu-Ni solder; wettability; coating

On-line weld quality inspection based on weld indentation by using servo gun ZHANG Xiao-yun, ZHANG Yan-song, CHEN Guan-long (School of Mechanical Engineering, Shanghai Jiaotong University, Shanghai 200030, China). p57—60

Abstract: Resistance spot welding (RSW) is the primary joining method for car-body assembly. Control and inspection of weld quality have great importance to improve the performance of car. Based on the position feedback characteristics of servo encoder, online weld quality inspection method was proposed by using weld indentation. A spot welding experimental system including robot, robot controller, servo gun and weld controller was integrated. The developed measurement program was used to acquie weld indentation online, and the measured results was calibrated by PLC displacement control system. The experimental results showed that the acquired weld indentation can reflect the real indentation on the 0.8mm low carbon steel (GMW2). The weld quality inspection rate can meet the demand for real production. The proposed on-line weld quality inspection method can meet the demand of welded joint measurement in real plant environment.

Key words: resistance spot welding; servo gun; weld indentation; on-line inspection

Method of welding groove feature design and weld feature recognition LIU Yong[1], WANG Ke-hong[1], DU Shan-shan[2], XU Yue-lan[1] (1, Material Department of Science & Engineer, Nanjing University of Science & Technology, Nanjing 210094, China; 2. Computer School of Science & Technology, Nanjing University of Science & Technology, Nanjing 210094, China). p61—64

Abstracts: To solve welding workpiece model, it is important to study welding groove feature design. The design requirements of welding groove were analysed in the numeric CAD/CAPP/ROBOTICS integrated welding. The total scheme was desiged to realize the data share between CAD design environment and CAPP/ROBOTICS environment. Firstly a method to model typical welding groove based on groove feature library was given, then a better method to model universal weld groove driving by program developing based on CAD/CAM platform was provided. And the method of welding groove feature and weld feature recognition was put forward. Example proved that it is correct.

Key words: welding groove; feature design; feature recognition

Fracture microstructures and properties of Al-Li alloy brazed joints ZHANG Ling, XUE Song-bai, SHI Huai-jiang, WU Yu-xiu (College of Materials Science and Technology, Nanjing University of Aeronautics and Astronautics, Nanjing 210016, China). p65—68

Abstract: Microstructures of base metal and brazed joints were analyzed using metallographic microscope, SEM and microhardness instrument and the changing rule of strength of brazed joints was studied by testing microhardness of brazed joints and chemical composition of fracture micro-section. The results show that shape of reinforcing phase of base metal are changed from particle to strip after brazing; there are few defects such as gas pores, slag inclusions, cracks and so on in brazed joints with N_2 atmosphere, which improves mechanical properties of brazed joints effectively, however there are many defects in brazed joints without N_2 atmosphere, which reduces mechanical properties of brazed joints seriously.

Key words: Al-Li alloy; brazed joint; microstructure; microhardness

Intelligent digital control system for CO_2 short circuiting welding FENG Yue-hai[1,2], LIU Jia[2], YIN Shu-yan[2], WANG Ke-hong (1. Department of Materials Science & Engineering, Nanjing University of Science and Technology, Nanjing 210094, China; 2. College of Mechanical Engineer and Applied Electronics Technology, Beijing University of Technology, Beijing 100022, China). p69—72

Abstract: For the shortage of short circuiting transfer for general CO_2 welding machine, based on the hardware system of digital signal processor and microprocessor control unit, the hierarchical intelligent control theory was applied and the hierarchicall intelligent full digital control schematic for CO_2 short circuiting transfer welding was put forward. It integrates the digital PI controller, fuzzy controller and expert system, which make control levels clearer and design scheme easier. The experimental results validate that this system can attain ideal waveform control for CO_2 short-circuit welding, and improve CO_2 welding machine performance, and control welding process intelligently.

Key words: digital control system; gas metal arc welding; hierarchical intelligent control

Numerical analysis of multi-pass welding residual stress for typical closed weld CHEN Hu, GONG Jian-ming, TU Shan-dong (Nanjing University of Technology, Nanjing 210009, China). p73—76

Abstract: Two typical closed weld, circular patch weld and nozzle weld, were modeled and 3-D multi-pass welding simulation were performed using FEM. User subroutine were used to realized the moving Gauss distribution of welding heat source. The thermal cycle and residual stresses distribution were obtained. The results show that