电阻点焊中电极位移的测量方法分析

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摘 要：简述了电阻点焊中传统的电极位移测量方法，包括直接测量方法、上电极运动测量方法和长臂工装测量方法. 通过有限元方法分析了焊钳在设定电极力和动态电极力作用下的变形，并分析了该变形对上电极运动测量方法和长臂工装测量方法的影响. 结果表明，因动态电极力的影响，使焊钳发生变形以及下电极发生相对较大垂直位移和偏转角，从而使上电极运动测量方法和长臂工装测量方法均无法准确测量电极位移值. 最后提出了梯形关系的电极位移测量方法.

关键词：电阻点焊；电极位移；电极力；测量方法；有限元
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0 序 言

电阻点焊以其高效率、低成本、高自动化程度等优点，在工业生产中有着相当广泛的应用. 然而电阻点焊是一个多因素耦合过程，其焊接质量容易受工件表面质量状况差、分流、磨损、飞溅等多种因素的影响，因此需进行电阻点焊质量的监控[1].

电阻点焊质量的监测中，电极位移被认为是一种比较直观的反应熔核大小的理想监控参数，能够对点焊过程中各种故障进行诊断，并利用电极位移曲线及其特征进行焊点质量的控制[2]. 但是电极位移监测方法因测量工装容易与被焊工件发生干涉而很少工程化应用，大多只用于实验室的原理性研究. 由对电极位移波动机理的研究引出的采用加速度传感器测量电极振动信号来监测电阻点焊质量的方法可以很好地进行线膨胀位移监测方法的工程化应用[3,4]，但该方法只能适用于交流点焊机，对于现代工业中先进的中频直流点焊机却无法应用.

文中通过有限元方法分析了电阻点焊中焊钳变形对电极位移测量值的影响，从而提出了新的电极位移测量方法.

1 试验方法

1.1 电极位移的直接测量方法

电极位移的直接测量方法一般指在实验室做原理性试验时，将位移传感器及其挡板紧贴上下电极安装，实时测量上下电极之间的距离变化[5]. 试验所用的焊接试样是按标准剪裁出来的小试片，焊接时不会与位移传感器的测量路线发生干涉[5].

1.2 电极位移的上电极运动测量方法

为了避免电极位移测量工装或路线与被焊工件在实际工程应用中发生干涉，有学者提出只测量上电极气缸活塞在点焊过程中的位移运动，并认为该测量值就是焊点的线膨胀位移值. Haefner 等人[6]和 Min[7] 均采用数字光学编码器测量上电极运动位移，如图1所示. Li 等人[8] 在机械手电阻点焊机 C 形焊钳上采用激光位移传感器测量上电极与气缸固定部位的相对位移.

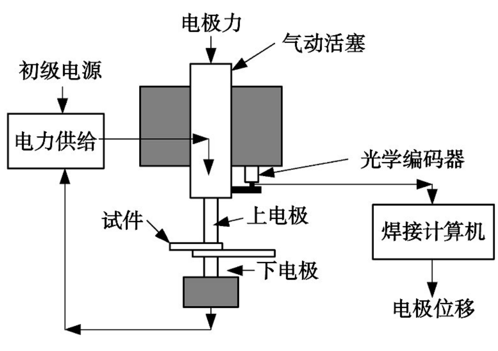

图1 电阻点焊的试验系统示意图

Fig. 1 Schematic diagram of experimental system for RSW

1.3 电极位移的长臂工装测量方法

为了既能避免位移传感器工装与被焊工件的干涉，又能测量上下电极之间的位移值，Xu 等人[9] 在电极位移直接测量方法的基础上，通过延长安装位

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移传感器的工装臂来达到上述目的; 同时为了校正因延长工装后上下工装臂不平行而导致的测量误差问题,采用在特定电极压力下,通过对不同厚度标尺的测量来校正电极位移测量值与真实值之间的关系,其测量工装实物图如图 2 所示.

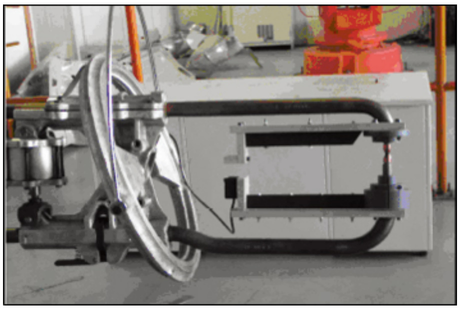


图 2 传感器安装实物图
Fig. 2 Sensor mounting diagram

2 试验结果和讨论

2.1 焊钳有限元模型及加载

实际上,在电极力的作用下,安装上下电极的焊机或焊钳的机械臂会发生变形位移. 文中以图 3a 所示不锈钢地铁车体的底架骨架焊接系统的 C 形焊钳为研究对象,进行焊钳变形的有限元仿真分析.

对 C 形焊钳进行初步简化后,采用 Hyper-Mesh 画分网格建立有限元模型,如图 3b 所示,并在上下电极上按焊接工艺参数加载电极力 18 kN,如图 3c,d 所示.

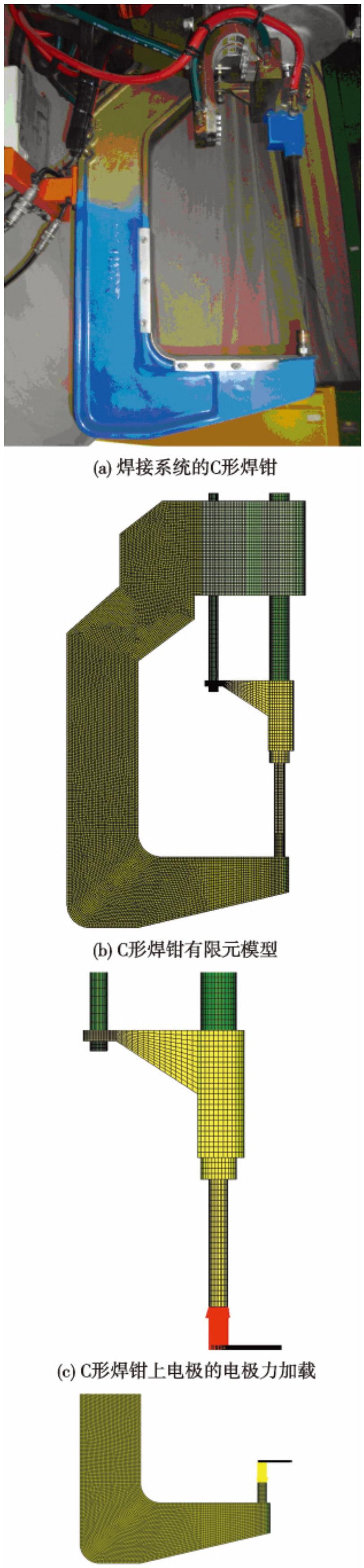
2.2 焊钳仿真结果

将在 Hyper-Mesh 软件中建立的焊钳有限元模型导入到 ANSYS 软件进行应力和应变分析,其结果如图 4 所示.

由图 4a 可知,焊钳最大应力出现在 C 形焊钳垂直臂上端内侧,最大值为 80 MPa,远小于铸铜的屈服强度 350 MPa. 由图 4b,c 可知,焊钳上电极臂基本没有变形位移,而下电极发生较大的垂向和纵向变形位移,即发生了一定的偏转角度,具体变形数据如表 1 所示.

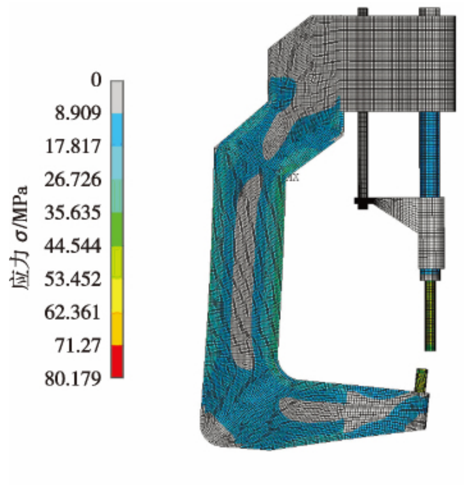
表 1 18 kN 电极压力时上下电极头部位移和偏转角度
Table 1 Displacement and deflection angle of upper and lower electrode tips under 18 kN

	垂向位移 s_1/mm	纵向位移 s_2/mm	偏转角度 θ/(°)
上电极	0.090 48	0.039 859	0.006 6
下电极	−1.103	−0.489 552	0.205 7

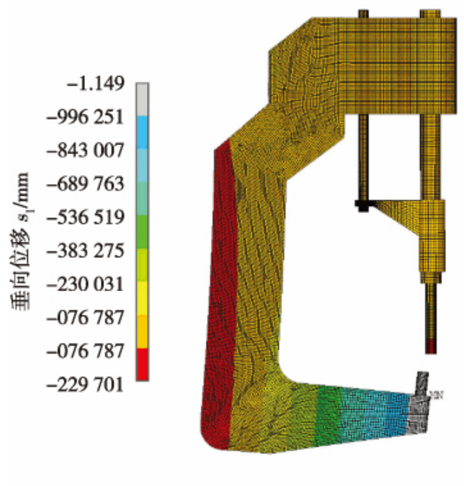


(a) 焊接系统的C形焊钳
(b) C形焊钳有限元模型
(c) C形焊钳上电极的电极力加载
(d) C形焊钳下电极的电极力加载

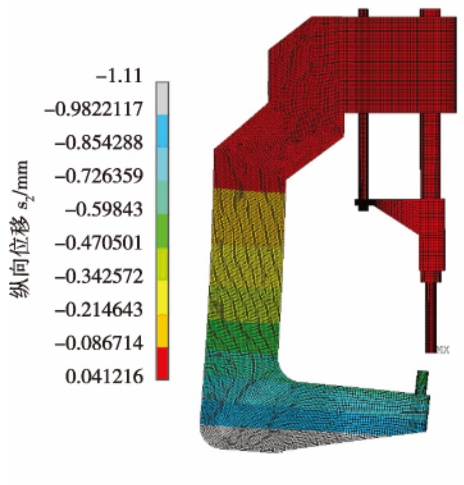
图 3 焊接系统的 C 形焊钳及有限元模型
Fig. 3 C type welding tong of welding system and its finite element model



(a) 焊钳应力云图



(b) 焊钳垂向位移云图



(c) 焊钳纵向位移云图

图 4　焊钳仿真分析结果

Fig. 4　Results of FEA for welding tongs

3　焊接过程中焊钳变形分析

Tang 等人[10]对钢的电阻点焊中电极力的特征进行了研究，结果表明电阻点焊过程中电极力并不是恒定不变的，而是比预设定值大，且呈指数函数曲线变化. 当电极压力的预设定值不同时，焊接过程中电极力的变化值也不同，其变化量在 5% 左右，如表 2 所示. 在焊机摩擦力和刚度相近时，其电极力变化情况类似. 这里取 5% 作为不锈钢车体焊接系统在焊接时电极力的变化量.

表 2　不同设定电极力下实际电极力的变化

Table 2　Force change under various preset forces

设定电极力 (lb)	600	800	1 000	1 200
$\triangle F$/(lb)	13	36	60	76
$\triangle F/F_D$(%)	2.3	4.7	6.0	6.1

当电极力增加 5%，即 18.9 kN 时，通过与第 2 节同样的焊钳变形仿真分析，其上下电极头部位移及偏转角度如表 3 所示.

表 3　18.9 kN 电极压力时上下电极头部位移和偏转角度

Table 3　Displacement and deflection angle of upper and lower electrode tips under 18.9 kN

	垂向位移 s_1/mm	纵向位移 s_2/mm	偏转角度 θ/(°)
上电极	0.090 08	0.041 844	0.007 0
下电极	-1.158	-0.514 072	0.216 0

4　电极位移的测量方法分析

比较表 1 和表 3 可知，由最大动态电极力引起的上电极头部垂直位移差为 0.4 μm，纵向位移差为 1.985 μm，偏转角度差为 0.000 4°，经长达 375 mm 的工装臂放大后垂直位移误差为 2.6 μm；下电极头部垂直位移差为 53 μm，纵向位移差为 24.52 μm，偏转角度差为 0.010 3°，经长达 375 mm 的工装臂放大后垂直位移误差为 67.4 μm. 因此，在动态电极力的作用下，由焊钳变形引起的上电极的动态垂向位移差和偏转角度差对于电极位移测量的影响可以忽略；而引起的下电极的动态垂向位移差和偏转角度差对于最大电极位移量小于 1 mm 的测量的影响是不可忽略的.

当采用上电极运动测量方法时，只测量了上电极的相对运动. 然而，在电阻点焊过程中，由于动态电极力的变化，使下电极发生较大的垂向脉冲位移运动，这样会使电极位移测量的下基准面发生动态变化，从而无法准确测量焊点的线膨胀位移.

当采用长臂工装测量方法时，虽然测量了上下电极间的相对运动，但是，由于焊接过程中动态电极

力的变化，使下电极发生相对较大的偏转角，从而使安装在下电极上的工装臂也会产生动态变化的且相对较大的偏转角，引起延长后的工装臂的测量端发生较大的测量误差，因此无法准确测量焊点的线膨胀位移.

5 电极位移的梯形关系测量方法

针对长臂工装测量方法存在的缺陷，提出采用梯形关系测量的方法来测量真实的电极位移，其测量原理如图5所示. 梯形关系测量原理是利用安装在下电极工装臂上的相距一定距离的两个位移传感器同时测量，当电极力发生变化时，焊钳臂发生形变，初始的上下电极上的工装臂的平行度发生变化，引起两个位移传感器测量值也发生变化，从而通过梯形关系计算出上下电极之间的距离，即

$$d_0 = \frac{b \cdot d_1 + a \cdot d_1 - a \cdot d_2}{b} \qquad (1)$$

式中：a 为第一位移传感器与下电极之间的距离；b 为第一位移传感器与第二位移传感器之间的距离；d_0 为上下电极之间的距离；d_1 为第一位移传感器的测量值；d_2 为第二位移传感器的测量值，真实的电极位移为两个传感器测量值的变化值经式(1)计算后的结果. 该测量方法可实时有效地克服因电极力变化引起的测量误差.

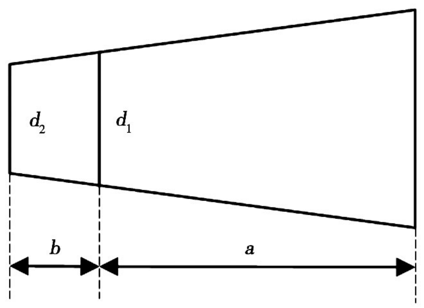


图5 梯形关系测量电极位移的原理图

Fig. 5 Schematic diagram of measuring electrode displacement using trapezoidal relaionship

6 结 论

(1) 经有限元分析，C形焊钳在电极力作用下会发生变形，使下电极发生较大的垂向位移、纵向位移和角度偏转.

(2) 在动态电极力的作用下，C形焊钳下电极发生相对较大的动态垂向位移运动，同时发生较大的偏转角，使上电极运动测量方法和长臂工装测量方法均无法准确测量电极位移值.

(3) 采用梯形关系测量原理可有效克服长臂工装测量方法的缺陷，从而能在工程应用中较准确地测量出真实的电极位移值.

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China; 2. China Petroleum Pipeline Bureau, Langfang 065000, China; 3. The Third Engineering Branch of China Petroleum Pipeline Bureau, Zhongmu 451450, China). pp 72 – 74

Abstract: This article develops tandem automatic welding system for pipeline according to the principle of tandem welding technology, develops efficient welding technology about "Internal welding machine for root welding and double wire automatic welding for filling and capping welding". Experiments indicate tandem automatic welding technology can avoid defects existing in pipeline welding construction effectively to ensure the welding quality, such as incomplete fusion, stomata, incomplete penetration, pipeline welding discontinuous and undercut. At the same time, it can increase the weld single – layer filling thickness from 2 – 3 mm to 4 – 6mm, and it can get beautiful welding gap, excellent mechanical properties. This technology can meet pipeline construction on the welding requirements of high efficiency, and has the application value and guiding significance for construction of oil and gas field welding of pipeline.

Key words: oil and gas pipelines; automatic welding; tandem welding; mechanical properties

Plasma arc welding pool edge detection based on empirical multi-parametersconstraint LIU Xinfeng, REN Wenjian, GAO Jinqiang, WU Chuansong, ZHANG Guokai (Key Laboratory for Liquid-Solid Structural Evolution and Processing of Materials, Ministry of Education, Shandong University, Jinan 250061, China). pp 75 – 78

Abstract: The algorithm to extractthe plasma arc welding pool edge was studied in this paper. Large area of the saturated region formed in weld poolimages because of reflected arc by weld pool surface. The gray gradient on the boundary of arc region is greater than that of the weld pool. So weld pool boundary can not accurately be extracted by the traditional image algorithms. Aiming at this problem, a multi-parameters constraint algorithm was proposed. The edge information of n frames processed weld pool images and arc minimum circumscribed curve were used as prior knowledge in the algorithm. The results show that the algorithm can effectively eliminate the pseudo boundary and weld pool edge can be detected well and quickly.

Key words: Plasma arc welding; vision detection; weld pool image; edge detection; multi-parameters constraint

Optimization of welding current waveform parameters in controlled short circuiting transfer GMAW CHEN Maoai, JIANG Yuanning, WU Chuansong (Institute for Materials Joining, Shandong University, Jinan 250061, China). pp 79 – 82

Abstract: For controlled short circuiting transfer GMAW, peak current I_{ap}, background arcing current I_{ab} and tail-out time t_w (time required for welding current to decrease from I_{ap} to I_{ab}) are the adjustable waveform parameters, which have significant influence on the process stability, spatter rate and weld appearance. Using orthogonal experiment method, waveform parameters were optimized at different wire feeding rate. The results show that peak welding current has the strongest influence among the three waveform parameters. At wire feeding rate of 320 cm/min, the spatter rate is more than 2.5%, the weld appearance is always rough and bad no matter what levels of the waveforms parameters were used. With the wire feeding rate varying from 360 to 400 cm/min, the optimal waveform parameters keep constant, i.e. I_{pa} = 440 A, I_{ba} = 50 A, and t_w = 0.6 ms. At wire feedingrate of 400 cm/min, the stable welding process with a spatter rate of less than 0.35% and excellent weld appearance can be achieved in quite wide ranges of waveform parameters (I_{pa} is 440 – 480 A, I_{ba} is 30 – 50 A, and t_w is 0.6 – 0.8 ms).

Key words: CO_2 arc welding; spatter; short circuiting transfer

Numerical simulation of pulsed laser welding temperature field for Al3003 aluminum alloy FU Guansheng, ZHENG Moujin (Ningbo CSR New Energy Technology Co., LTD., Ningbo, 315000). pp 83 – 86

Abstract: The pulsed laser welding temperature field for supercapacitor shell structure was analyzed by FEM. The welding heat model parameterswere defined based on the macrostructure of the welded joint taken from the real component. The thermalconductivity andspecific heat were tested to obtain the thermodynamic parameter, respectively. Thehigh temperaturemechanical propertiesat 3 different temperatureswere tested, and the melting point is predicted to analyze the FEM calculation result. The result shows that the pulsed laser welding energy is more concentrated than that of arc welding, the core inside the supercapacitor and the rubber component will not be destroyed by high welding temperature during the whole welding process.

Key words: supercapacitor; laser; numerical simulation; pulse

Analysis of electrode displacement measurement method in resistance spot welding WANG Xianfeng, YANG Ying, WANG Guojun, WANG Xuefang (CSR Zhuzhou Electric Locomotive Co. Ltd., Zhuzhou 412001, China). pp 87 – 90

Abstract: The traditional methods to measure the electrode displacement in resistance spot welding include direct measurement method, measurement of upper electrode movement, and measurement of long arm tooling. The deformation of welding tongs was analyzed by finite element method (FEM) under the load of electrode force and dynamic electrode force. And the deformation influence on measurement method of upper electrode movement and measurement method of long arm tooling was analyzed. It is concluded that the lower electrode has relative larger vertical displacement and deflection angle for dynamic electrode force, so the electrode displacement cannot be measured correctly using measurement method of upper electrode movement and measurement method of long arm tooling. At last, the method to measure electrode displacement was proposedbased on trapezoidal relationship.

Key words: resistance spot welding; electrode displacement; measurement method; FEM