

基于 USB 接口的超声 TOFD 检测系统研制及其应用

盛朝阳¹, 刚 铁¹, 迟大钊¹, 黄江中¹, 李宜男², 赵卫君²

(1 哈尔滨工业大学 现代焊接生产技术国家重点实验室, 哈尔滨 150001;

2 哈尔滨锅炉厂有限责任公司, 哈尔滨 150046)

摘 要: 为了定量检测厚壁焊接结构中的缺陷, 对基于 USB 接口的便携式超声衍射时差法 (TOFD, time of flight diffraction) 的缺陷检测及定位系统进行了研究. 为了便于缺陷的定量及定性识别, 引入了信号互相关算法, 实现了检测图像的校正. 利用该检测系统进行了锅炉压力容器焊缝的检测. 结果表明, 该系统所获得的 D 扫描图像清晰、直观、易分辨, 同时较准确地确定了缺陷位置, 信号互相关算法很好地解决了检测图像不连贯的现象.

关键词: 超声衍射; 焊缝检测; 信号采集; 压力容器检测; 图像校正

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盛朝阳

0 序 言

焊接是压力容器制造的主要加工手段之一. 对于壁厚达几十甚至上百毫米的压力容器, 常规的检测方法如磁粉, 渗透, 涡流只能是近表面缺陷的检测, 射线检测对裂纹的检测能力有限, 而传统超声检测在缺陷定量方面采用当量法, 不是缺陷真实的尺寸, 这样不利于后续的质量评定. 随着超声成像检测技术的发展, 超声 TOFD 方法以其原理简单, 操作方便, 检测结果易存储, 对裂纹类缺陷敏感等特点越来越受到人们的青睐^[1-3]. 目前欧美地区的一些国家和日本已经将该方法应用于长管道及压力容器的检测, 同时推出了相应的检测标准^[4,5], 而在国内该技术的应用刚刚兴起, 学者们广泛研究了 TOFD 技术成像原理、信号分析、图像判读、检测工艺等^[6,7]. 目前已有公司生产并销售超声 TOFD 检测系统, 但这些系统对于用户都是封闭的, 用户不能够根据自己的需要添加功能, 同时价格也比较昂贵. 所以开发操作简单方便, 结构灵巧的超声 TOFD 检测系统是非常有必要的.

根据超声 TOFD 检测的基本原理, 借助于 USB 接口的超声波采集卡进行开发, 实现检测信号的采集与数据的存储; 设计现场检测操作方便的扫查架. 同时采用信号互相关的算法校正检测图像, 利用开

发的系统检测了实际焊缝, 获得的图像清晰, 并初步确定了缺陷的位置, 结果比较理想.

1 超声 TOFD 检测原理及系统的开发

1.1 超声 TOFD 检测原理

超声 TOFD 方法^[8]是利用一个发射探头、一个接收探头进行检测的, 两探头相向布置在焊缝两侧且探头中心在同一直线上. 该方法通常使用纵波探头, 它是利用超声波在缺陷端部发生衍射现象, 根据探头接收信号时间的不同, 计算出缺陷的位置.

TOFD 方法的 D 扫描图像可初步确定缺陷的长度及深度. 缺陷长度由探头移动量直接给出; 缺陷埋藏深度为

$$d = \frac{1}{2} [(c \Delta t)^2 + 4 \Delta t^2]^{\frac{1}{2}} \quad (1)$$

式中: c 为纵波声速; Δt 为侧向波与衍射波之间的传播时间差; Δ 为 $1/2$ 的探头间距. 当缺陷自身高度较大时, 可分别计算出上下端的埋藏深度, 从而求得缺陷在板厚方向的高度.

1.2 系统硬件组成

系统硬件包括: 附有计数器功能的 USB 超声波采集卡、笔记本电脑、前置放大器. 笔记本电脑主要用于控制系统工作, 存储数据, 同时对 USB 超声采集卡进行供电. 基于 USB 接口的超声波采集卡是系统的核心, 其主要作用是发射及接收超声波, 同时将模拟信号转换为数字信号, 该卡还集成了计数器功

能. 由于现场检测的工件厚度可达到 100 mm, 随着工件厚度的增加, 超声波能量衰减严重, 这使得检测得到的 A 信号能量也较低, 这样不利于发现微弱的衍射信号, 所以在开发系统的结构中加入了放大器模块, 它将接收到的 A 信号放大后输入超声波采集卡的接收通道, 同时可提高信号的信噪比. 图 1 为系统工作示意图.

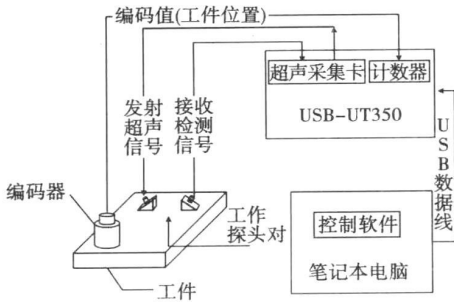


图 1 系统工作示意图

Fig. 1 Schematic of system

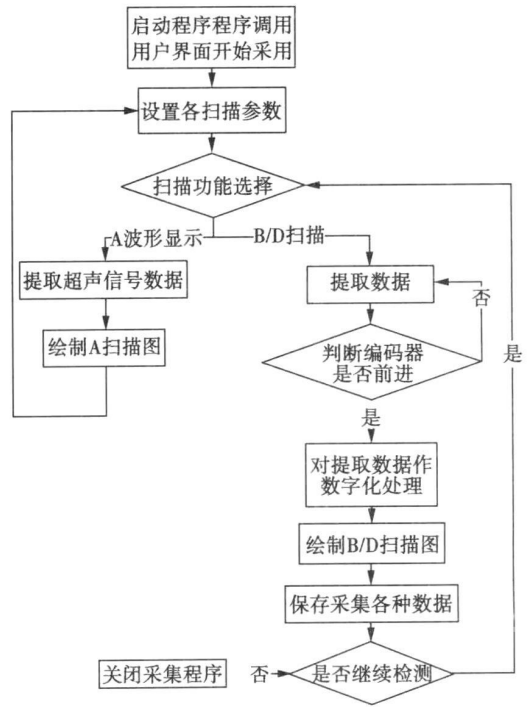


图 2 检测软件流程图

Fig. 2 Flowchart of testing software

1.3 软件设计基础

系统软件的功能主要有三部分: 一是检测参数调节, 如采样频率、系统增益、时间延迟、采样点数等; 二是操作功能选择, 包括图像显示类型选择, 保存数据、图像等功能; 第三部分是检测图像显示区, 以位图形式显示扫描结果, 方便人员实时监测, 同时有利于调整检测参数. 信号采集是整个软件的关键步骤, 只有准确可靠地采集 TOFD 检测信号, 才能够判断焊缝是否有缺陷以及缺陷的位置. 在系统程序控制下, 同步采集 A 扫描信号和探头位置信号. 提取信号后, 将采集结果以二维图像形式实时显示, 即 TOFD 方法的 D 或 B 扫描图. 其横坐标代表探头位移, 每一列代表一个 A 扫描信号. 系统 A 扫描信号各点幅值在 0 ~ 255 之间, 直接利用 A 信号的幅值数据作为图像的灰度值生成灰度图. 随着探头的移动控制 TOFD 图像的生成, 最终完成整幅 TOFD 图像显示. 软件流程如图 2 所示.

1.4 便携式检测装置设计

对于工作现场, 需设计结构简单, 操作方便的 TOFD 扫描装置. 同时要保证焊缝中缺陷检测的精度、准确性以及检测效率. 该装置主要有两部分组成: 即探头夹具及位置信息提取装置. 系统采用半自动的检测结构, 即信号的采集与记录是自动进行的, 而探头装置的行走机构是手动的, 只要操作人员在推动探头行走的过程中保持较平稳, 就可以完成自动检测与信号采集.

位置提取装置采用编码器, 它将位置信号传输到计算机中与检测信号同时存储, 实现精确定位. 探头夹具设计主要是确保两探头相对布置且移动一致. 开发系统如图 3 所示.

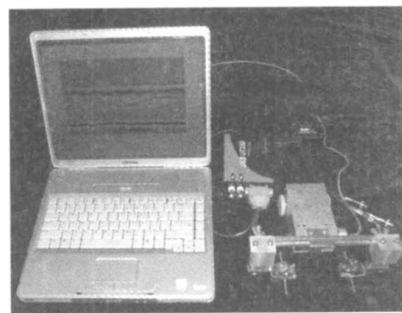


图 3 开发的 TOFD 检测系统

Fig. 3 Developed TOFD testing system

2 基于信号互相关的图像校正

在检测过程中, 由于工件表面不平等原因, 使得采集的图像可能存在波形不连续的现象, 图 4 为 24 mm 厚的实际焊缝检测图像, 可以发现部分图像发生畸变. 根据理论知识可知, 在相同厚度的情况下, 检测的 D 扫描图像的侧向波及底面回波应在同一

水平位置. 而图 4 中侧向波及底面回波发生了了变形, 偏离了正常的位置, 同时缺陷的衍射波也发生了畸变, 这使得扫描图像成像缺乏连贯性, 不利于缺陷的识别.

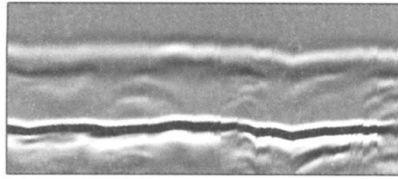


图 4 侧向波不连续的 D扫描图像

Fig. 4 D-scan image with distorted lateral wave

超声 TOFD检测的 D扫描图像是多个 A信号按照探头行走位置的堆垛, 其横坐标代表探头位移, 一纵列代表一个 A扫描信号, 所以调整位置发生变化的 A信号, 即可实现整幅图像的校正.

在信号的相关分析中, 互相关函数完整地描述了两信号之间的相关情况或取值依赖关系. D扫描图像中不同的 A信号的侧向波及底面回波的位置是相同的, 不同的是缺陷衍射波的位置, 所以不同的 A信号在幅值上存在依赖关系, 可以利用这一性质进行检测, 即两个信号的相关函数取得最大值时是两信号位置基本相同, 波形最相似的情况.

设 $x(n)$ 和 $y(n)$ 为两个能量有限的确定性离散信号, 其互相关函数为

$$R_{xy}(m) = \sum_{n=-N}^N x(n) y(n+m) \quad (2)$$

式中: m 表示移位的位数.

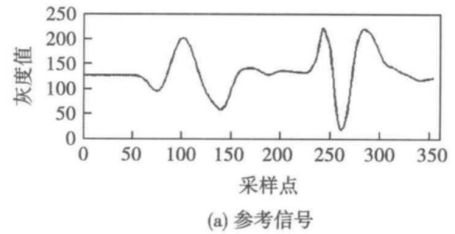
利用信号互相关方法校正 TOFD图像的步骤如下: (1) 确定进行互相关运算的参考信号 $x(n)$ 及互相关运算点数 M ; (2) 将每一个 A信号 $y(n)$ 与 $x(n)$ 进行互相关计算, 并寻找互相关函数值的最大位置; (3) 将最大位置换算成相应的延时点 m_{max} ; (4) 按延时点平移信号 $y(n)$.

将每一列 A信号与参考信号 $x(n)$ 进行上述运算, 即可完成图像校正. 在利用互相关算法校正检测图像过程中涉及到参考信号选取的问题. 将一幅图像中所有 A信号的均值作为参考信号. 利用上述算法校正图 4 图 5 a 为参考信号, 图 5 b 为校正后的图像.

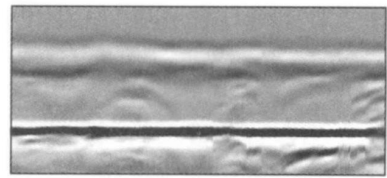
3 实际焊缝检测

利用开发的超声 TOFD检测系统, 进行焊接结

构的现场检测. 该焊接结构为锅炉制造中的纵缝厚壁结构, 材料为低合金钢, 厚度约为 70 mm. 检测的系统参数为: 探头频率为 2.25 MHz, 采样频率为 25 MHz, 探头间距 2θ 为 145 mm, D扫描步进为 0.28 mm. 图 6 a 为检测的原始图像, 校正后的 D扫描图像如图 6 b 所示, 可发现侧向波及底面回波明显被校正, 且图像中存在两处缺陷, 缺陷的位置靠近焊缝底部, 深度分别为 53.37 和 61.36 mm.



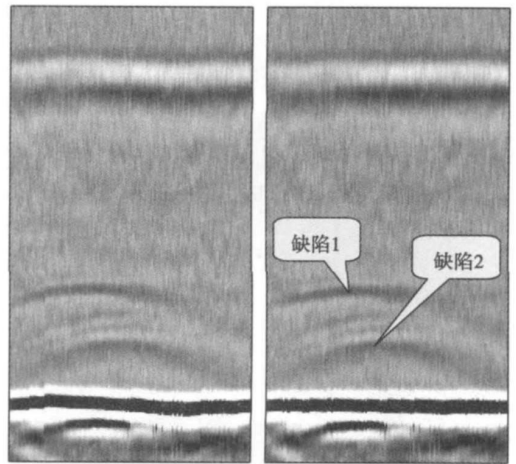
(a) 参考信号



(b) 校正后图像

图 5 D扫描图像校正

Fig. 5 Correction of D-scan image



(a) 原图像

(b) 校正图像

图 6 焊缝检测及校正结果

Fig. 6 Results of weld testing and correction

7 为电弧气刨技术将焊缝剖开后所呈现的形貌片, 焊缝中明显存在夹渣缺陷, 与检测结果基本吻合. 从图 6 b 校正的 D扫描图像结果可以看出, 开发的基于 USB接口的 TOFD检测系统及相应的图像校正算法能够应用于厚壁压力容器的缺陷检测, 并且检测图像清晰, 缺陷易辨识.

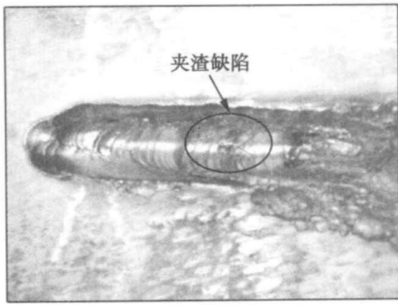


图 7 解剖检验的焊缝形貌

Fig. 7 Weld appearance after dissection test

4 结 论

(1) 基于 USB 接口的便携式 TOFD 检测系统, 其检测图像清晰、直观、易分辨。

(2) 利用互相关算法对检测图像进行了校正, 提高了图像的连续性及可读性, 有利于缺陷的定量及定性识别。

(3) 与传统的实验室 TOFD 检测设备相比, 该系统工作环境的适应性强, 携带方便, 操作更简单, 经济实用, 并且是开放的, 可以根据不同的需要进行升级。

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作者简介: 盛朝阳, 女, 1982 年出生, 博士研究生. 主要从事超声波无损检测科研. 发表论文 2 篇. Email: shzhyl001@sina.com

通讯作者: 刚 铁, 男, 教授. Email: gang@hjt.edu.cn

MAIN TOPICS, ABSTRACTS & KEY WORDS

Aging embrittlement of Super 304H steel welded joint LI Ximei, ZOU Yong, ZOU Zengda, ZHANG Zhongwen (1. Key Laboratory of Liquid Structure and Heredity of Materials, Ministry of Education, Shandong University, Jinan 250061, China; 2. Shandong Electric Power Research Institute, Jinan 250002, China), P 1—4, 24

Abstract The embrittlement of welded joints of Super 304H steel was investigated by means of scanning electron microscopy, energy dispersive spectroscopy, transmission electron microscopy, X-ray diffraction analysis and the impact test. The experimental results indicate that the microstructure of welded joints consists of matrix and precipitated phase. The reason of embrittlement of welded joint is that $Cr_{23}C_6$ precipitated along coarse grain boundary and the amount of precipitation are the key factors. After being aged at 650 °C, there are obvious precipitated Nb(C, N) and $Cr_{23}C_6$ phases in welded joint and the amount of precipitate reaches a stable value with the increasing of aging time. The precipitation of $Cr_{23}C_6$ causes the intergranular embrittlement of welded seam, the impact energy of welded joint reduces rapidly and the fracture mode turns to intergranular fracture. The toughness of welded joint of Super 304H steel depends on the microstructure of the matrix under welded condition.

Key words aging treatment, austenitic steel, welded joint, embrittlement

Effect of laser remelting on erosion behavior of plasma sprayed thermal barrier coatings WANG Dongsheng², TIAN Zongjun², WANG Jingwen¹, SHEN Lidai², HUANG Yinhu² (1. Department of Mechanical Engineering, Tongling College, Tongling 244000, China; 2. College of Mechanical and Electrical Engineering, Nanjing University of Aeronautics and Astronautics, Nanjing 210016, China), P 5—8

Abstract The $ZrO_2-7\% Y_2O_3$ thermal barrier coatings fabricated by plasma spraying on TiAl alloy surface were remelted by laser. The microstructures of the plasma sprayed and laser remelted coatings were compared by using scanning electron microscopy (SEM). Meanwhile, the erosion experiments of the coatings were carried out and the erosion failure mechanisms were discussed. The results show that the as-sprayed ceramic coating has a typical lamellar stacking characteristic. However, the laser remelted coating exhibits a compact remelted zone which is composed of column-like grains along the direction of the heat current. The laser remelted coating has better erosion resistance than the plasma sprayed coating. Both as-sprayed and laser remelted coatings show a brittleness erosion mechanism. Owing to the limited bonding at the interfaces between lamellar the spalling of ceramic particles from the lamellar interface may

be mainly responsible for the erosion of the as-sprayed coating. In contrast, cracking occurs within region near the surface of the laser remelted ceramic coating which makes erosion occur by removal of these small blocks.

Key words laser remelting, plasma spraying, thermal barrier coatings, erosion resistance, failure mechanism

Development and application of ultrasonic TOFD testing system with USB SHENG Zhaoyang, GANG Tie, CHI Dazhao, HUANG Jiangzhong, LI Yinan, ZHAO Weijun (1. State Laboratory of Advanced Welding Production Technology, Harbin Institute of Technology, Harbin 150001, China; 2. Harbin Boiler Company Limited, Harbin 150046, China), P 9—12

Abstract A testing system based on expanded ultrasonic TOFD (time of flight diffraction) with USB was presented for thick-walled weld inspection. And the cross-correlation algorithm was used to correct the distorted testing image for defect identification. The system was applied on the boiler weld testing at the workshop. The results show that the D scan image is clear and the defects can be recognized quickly. The distortion of testing image was well avoided by cross-correlation algorithm. The developed system is open, which can be updated according to the requirement. The testing processing can be easily implemented. So the system is suitable for weld detection and could provide referenced data for the quality evaluation of weld.

Key words ultrasonic diffraction, weld testing, signal collection, pressure vessel testing, image correction

Resonance phenomenon of small current pulsed TIG arc and analysis of AC impedance features NIU Yong, SONG Yongjun, ZENG Zhoudo (1. State Key Laboratory of Precision Measurement Technology and Instruments, Tianjin University, Tianjin 300072, China; 2. College of Mechanical Engineering & Applied Electronics Technology, Beijing University of Technology, Beijing 100124, China), P 13—16

Abstract A method that alternating sine current superposes on direct current was adopted for study on alternating current impedance of the small current TIG arc. It was found that with the frequency getting high, the modulus of arc impedance increased and then decreased, and the phase angle decreased continuously. The maximum of the modulus just coincided with the zero point of phase angle, and obviously arc impedance had a resonance. By analyzing the voltage and current data in many different frequencies, the electronic model and transfer function of TIG arc alternative component were deduced. The parameters of transfer function were fit by using mathematics software, and the resonance frequency was calculated.

Key words pulsed arc, arc modulus, resonance, dy-