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Strategies for monitoring and control with seam tracking in electron beam welding

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Abstract

Nowadays high qualities welds which have a very narrow form and high accuracy can be obtained with advanced monitor and control system. In this paper are presented the main components of the electron beam welding equipment CTW 5/60 and proposed two welding strategies with seam tracking and adapted to the possibilities of the experimental setup. The first strategy consists in dividing the surface of the material over several successive frames, while the second strategy involves performing the operation in a single pass. Aspects of machine vision, meaning the image reconstruction, seam detection and image processing methods are also summarized.

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Keywords: electron beam welding; electron beam control; seam tracking; welding automation; welding monitoring and control.

1. Introduction

Electron beam welding (EBW) is a nonconventional material processing commonly used for joining stainless steels, superalloys and reactive or refractory metals. Electron beam equipments are built also for other technological processes as melting, evaporation, refining, and thermal surface treatment. In fact, electron beam and laser are the only ways of delivering large amounts of concentrated thermal energy to materials (maximum 10^8 W/cm^2).

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Nuclear technologies, aeronautics, microelectronics are examples where such equipments are a necessity. High resolution, high power density and high depth/width ratio are just a few of the special properties that make the electron beam (EB) a powerful tool especially where conventional techniques proved to be inefficient. [1-5]

Unfortunately electron beam welding involves many complex phenomena like electrons generation, beam forming and transport, focusing and deflection, heat absorption in the material when the beam irradiates on a workpiece. All this leads to rapid melting and vaporization, resulting in a deep and narrow keyhole surrounded by fusion-solidification zone. Depending on the power density of the main beam, the boiling and explosion phenomena may occur. So, electron beam equipment is a multivariable, complicated and dynamic system with many parameters that need to be monitored and controlled. Today modern digital equipments, sometimes multitasking and distributed, allow modeling and simulation, monitoring and viewing of the electron beam welding process, real-time modification of different technological parameters. [4,5]

To study the complex phenomena various analytical models and solutions were used for the simulation of the heat source, temperature distribution during the electron beam welding and weld shape in [6-8] or for the prediction of vaporizing time curve in [9]. A numerical model for three-dimensional (3D) heat transfer and fluid flow in keyhole mode electron beam welding was developed in [10]. Lindgren actually presents a review of different analytical models in [11] and describes the application of the finite element method to predict the thermal, material and mechanical effects of welding [12]. Several authors [12-15] have used the finite element method (FEM) to analyze heat flow in welds and to overcome the limitations of the analytical models. They obtained a better estimation of the thermal field, weld pool geometry, transient temperature, heat affected zone, residual stresses and distortion. Sometimes the results are experimentally validated and allow optimization of the process technological parameters.

It is obvious in these studies that a small change in beam spot diameter of electron beam greatly modifies the power distribution and alters the heat transfer. The directing components of the electron beam gun influence the quality of the weld, which is a sufficient reason for being detailed. The paper [16] contains a simulation of the beam trajectory which crosses the focusing system, while mathematical models in [17] allow calculation of deflection and focus distances. Additionally in [18,19] the authors designed regulators for the two directing components that allow 3D control of the electron beam focal spot.

The examination of the electron gun variables is very difficult due to the nature of the process. The heating process depends on the electrons emission, electromagnetic fields, X radiation, material proprieties, etc. Thus it is a necessity the implementation of modern strategies implemented on digital devices to produce material processing at high quality and required standards. The use of sensors in the electron beam irradiation area is difficult due to multiple phenomena occurring. Depending on the type of the electron beam equipment there are different methods for monitoring and improvement of the material processing. In [20] a number of different EB probe devices have been developed to enable measurement of electron beam characteristics. Control methods of electron beam focus position according to the absorbed power in workpiece, breaking current, X radiation emitted or secondary electrons are presented in [21-23] and [24] treats the melting zone during EBW through analysis of the secondary current in the plasma. Authors of [25,26] exposed some principles of offline or online seam detection, before or during the welding, while [27,28] contain more advanced automatic seam tracking based on machine vision methods.

Considering the above and having the experience of the previous scientific works [8,17-19,27], in the present paper two strategies of welding monitoring and control based on seam tracking are developed. These are divided into several stages. The information about workpiece are obtained using the electrons reflected from the material surface and the weld joint is detected after processing the digital images from the image capturing system of the equipment [27]. The control and the seam tracking are done with the help of focusing and deflection components of the EB equipment [17-19].

2. Electron Beam Welding Equipment

The most common systems of this type used in manufacturing are high vacuum design. The main parts of the equipment are the triode gun and the vacuum system that provides high vacuum environment (pressure level of 10^{-3}-10^{-4} Pa). Both are controlled by a multitasking digital system.