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Monitoring of varying joint gap width during laser beam welding by a dual vision and spectroscopic sensing system

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Abstract

A vision and spectroscopic system for estimation of the joint gap width in autogenous laser beam butt welding is presented. Variations in joint gap width can introduce imperfections in the butt joint seam, which in turn influence fatigue life and structural integrity. The aim of the monitoring approach explored here is to acquire sufficiently robust process data to be used to guide post inspection activities and/or to enable feedback control for a decreased process variability. The dual-sensing approach includes a calibrated CMOS camera and a miniature spectrometer integrated with a laser beam tool. The camera system includes LED illumination and matching optical filters and captures images of the area in front of the melt pool in order to estimate the joint gap width from the information in the image. The intensity of different spectral lines acquired by the spectrometer has been investigated and the correlation between the intensity of representative lines and the joint gap width has been studied. Welding experiments have been conducted using a 6 kW fiber laser. Results from both systems are promising, the camera system is able to give good estimations of the joint gap width, and good correlations between the signal from the spectrometer and the joint gap width have been found. However, developments of the camera setup and vision algorithm can further improve the joint gap estimations and more experimental work is needed in order to evaluate the robustness of the systems.

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1. Introduction

This paper addresses the challenge of in-process monitoring of the joint gap width in autogenous laser beam welding (LBW) of butt joints by a vision and spectroscopic sensing system. The reason for exploring this issue is that imperfections in a butt weld seam due to variations in the joint gap width have an influence on the fatigue life and

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structural integrity. This in turn has a direct negative effect on the quality and service life of the welded structure. Important mechanisms behind the variation in gap width are heat induced distortion and wide fit-up tolerances in the included plate members. These situations are very common in industrial welding production. The aim of the monitoring approach explored is to acquire sufficiently robust process data to be used either to guide post inspection activities or to enable feedback control for a decreased process variability, or both. One typical problem that exemplifies the situation with variations in the joint gap width is that a too wide gap will reduce the weld strength because it will cause an underfill or undercut. This gives either a reduced weld area or unwanted geometrical features in the seam that could act as a stress riser. Another example of a typical problem is that a too wide gap can cause spatter in critical applications such as in stainless steel tube welding where one cannot tolerate spatter on the inside of the tube due to function.

In-process monitoring of LBW has been explored by many researchers and for many purposes during several decades. One major field is directed toward joint tracking systems utilizing cameras and sometimes projected light. Different concepts and principles regarding sensors for joint tracking are presented by Regaard et al. (2010), where a multi sensor concept is introduced, using a CMOS camera and a low power laser source for illumination, for tracking and also for measuring the displacement between the LBW tool and the work piece. Krämer et al. (2014) use a CMOS camera to capture images during LBW. A texture based algorithm is suggested where the difference in surface texture of the two work pieces is used to find the joint position. The method shows good results, but a teaching procedure is required for each test case, and the algorithm is expensive in terms of computational power, which makes it unsuitable for real-time applications. A combination of 2D feature extraction and 3D laser triangulation measurements is presented by Huang et al. (2012) to find narrow weld joint gaps. Gao et al. (2012) use an infrared camera, placed off-axis, for joint tracking during fiber LBW. The method showed promising results, but integrating a bulky camera system off-axis may not be an option in an industrial implementation. An online measurement system based on multiple sensors, i.e. embedding photodiodes, spectrometers, visible imaging and X-ray imaging has been proposed by You et al. (2015) in order to monitor the welding status. Luo and Shin (2015) present a vision system and develop an image processing algorithm to monitor the seam width.

As regards systems utilizing plasma spectroscopy, Ancona et al. (2001) demonstrated a correlation between the LBW plasma electron temperature and the weld quality. Sibillano et al. (2005) performed a correlation analysis of the welding plasma emission spectra and revealed that the dynamics of the plume is strictly related to the stability of the process. Based on these results, several signals, like e.g. the correlation coefficient between lines of different elements, as shown by Sibillano et al. (2007), or the plasma electron temperature, shown by Sibillano et al. (2009), have been extracted from the optical spectra to detect in real time the occurrence of weld defects. Although it has been successfully demonstrated that such spectroscopic signals can be used to predict, Sibillano et al. (2012 a), and control, Sibillano et al. (2012 b) in real time the penetration depth during laser lap joint welding, by acting on the laser power, this kind of approach has not been investigated yet for monitoring of the joint gap width.

In this paper, we present experimental results from a dual-sensing approach including a calibrated CMOS camera and a miniature spectrometer. Signal processing algorithms have been developed to extract information from the acquisitions from the two devices. The detection reliability by redundant information, and detection capability by complementary information will benefit from this. The limitations of the two respective sensing methods are discussed together with their complementarities looking for the development of a hybrid sensing system combining data from both devices. The purpose of this work is to give a proof of concept and also to make an investigation of the technical possibilities and limitations with in-process monitoring of the joint gap width. Special attention has been paid in order to adopt the experimental conditions to conform to industrial welding conditions.

2. Experimental setup

2.1. Laser system and weld material

The LBW tool manipulation is conducted using an industrial robot, ABB IRB4400. The LBW cell is equipped with a 1070 nm wavelength Ytterbium Fiber Laser (YLR-6000-S), from the manufacturer IPG, with 6 kW laser power. The LBW tool, from Permanova Laser System AB, consists of a collimating lens with 160 mm focal length and a