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Detection of micro gap weld joint by using magneto-optical imaging and Kalman filtering compensated with RBF neural network

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An approach for seam tracking of micro gap weld whose width is less than 0.1 mm based on magneto optical (MO) imaging technique during butt-joint laser welding of steel plates is investigated. Kalman filtering(KF) technology with radial basis function(RBF) neural network for weld detection by an MO sensor was applied to track the weld center position. Because the laser welding system process noises and the MO sensor measurement noises were colored noises, the estimation accuracy of traditional KF for seam tracking was degraded by the system model with extreme nonlinearities and could not be solved by the linear state-space model. Also, the statistics characteristics of noises could not be accurately obtained in actual welding. Thus, a RBF neural network was applied to the KF technique to compensate for the weld tracking errors. The neural network can restrain divergence filter and improve the system robustness. In comparison of traditional KF algorithm, the RBF with KF was not only more effectively in improving the weld tracking accuracy but also reduced noise disturbance. Experimental results showed that magneto optical imaging technique could be applied to detect micro gap weld accurately, which provides a novel approach for micro gap seam tracking.

1. Introduction

Laser welding has been widely used for its advantage in narrowly focusing laser radiation on a small area and high intensity heat source, which can obtain deep penetration and improve mechanical properties. As one of the key issues in laser welding process, seam tracking technique is critical to the weld quality. Among many sensing methods, machine vision systems have been widely used and developed for different manufacturing processes [1–4]. Nowadays arc sensor and vision sensor are widely used for seam tracking. The principle of arc sensing technique is that the distance fluctuation between the welding electrode and the weldment will cause arc voltage change [5]. The position of torch can be adjusted to the groove center of weld by an automatic voltage feedback controller. This technique can only be used in arc welding of groove and fillet weld. The most popular visual method for weld detection is relied on structured light technique [6]. Based on the principle of optical triangulation, a structured light stripe is projected on the weld surface and a camera is used to capture

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the cross-line between light stripe and weld. When there is a gap or deformation at weld joint, the strip light will be changed to reflect the groove shape, depth and location of weld. According to the changed information and image processing the weld position can be obtained and tracked. However, with regard to a laser butt joint welding where the weld gap is less than 0.1 mm, the gap is so narrow that the reflected light deforms too small to measure the weld joint.

Based on infrared images of the weld molten pool and keyhole, weld detection technique is also researched for laser welding [7]. An infrared visual image sensor is used to capture weld molten pool and to obtain weld center information, which is directly dependent on the weld external geometry or texture features. The thermal radiation information of weld can be captured by an infrared camera. However, when weld gap is less than 0.1 mm, the molten pool infrared image does not appear weld features, the position of micro gap weld center can not be determined [8]. Ultrasonic sensor can also be used to track the seam [9]. When an ultrasonic acoustic propagation encounters the weldment surface, the signal will be reflected and received by the ultrasonic sensor. The vertical distance between the sensor and the weldment can be obtained and the relative positional relationship between the weld and the torch can be calculated. Ultrasonic sensor is easily affected by temperature, density, pressure and other factors, which produces a greater measurement error. Coaxial visual inspection method can be applied in the laser weld seam detection. The principle of dichroitic mirror is used to design an image acquisition means to collect the weld magnified image below the laser beam directly [10]. Using a camera to capture the weld image during laser welding, the weld position can be determined by high multiples of magnified images. However, the weld gray images change so small in a butt joint welding that it is difficult to identify the position of micro gap weld. Though a microscope can be used to detect micro gap weld, the distance between lens and weldment surface changes due to welding mechanism vibration and weldment heat distortion, focal length will cause weld image blurring and the weld position can be hardly detected. At present, there is no effective detecting and tracking methods for a micro gap butt joint welding.

Magneto optical imaging (MOI) technology has been studied and approved for the cracks inspection in aging aircraft [11]. This technique has high accuracy and efficiency in measuring and imaging the magnetic field distribution. As a newly nondestructive test method, it gives the inspector an ability to quickly generate images in aviation material surface and subsurface fine cracks in real-time. MOI is a combination technique of Faraday and electromagnetic effects (magnetic flux leakage(MFL) or vortex). MOI was proposed by Fitzpatrick and Shih et al., and become attractive over the past decades. Many research works about MO physics with image processing of MOI systems has been conducted [12–14]. These studies are mainly used in inspection of aircraft rivets and the cracks of other materials. The characteristics of micro gap weld in laser welding process are different from those reported in the above-mentioned literatures.

Using MOI technology to detect weld position can effectively avoid the influences of spatters and light radiation in laser welding process. Experimental results indicated that the MOI technique could be applied to detect micro gap weld with high accuracy [15,16]. In fact, there still exist various noises such as magnetic domain noise, background light noise, measurement noises and system noises during laser welding. In order to obtain the information of micro gap weld, a nondestructive MO sensor is placed above the weldment. By driving a precisely three degrees of freedom x-axis , y-axis and z-axis servo motors, the vertical distance was adjusted very small between MO sensor and weldment surface. The closer the distance between MO sensor and weldment surface was, the clearer the MO image was. During actual welding, a laser beam spot was focused on the weld center, and the laser radiation was absorbed and the metal melted at the interface. The weldment usually had a weak vibration which caused the distance between MO sensor and weldment to change accordingly. This would affect the quality of weld MO image. Using MO sensor to detect weld should sustain in a constant magnetic field. Under different magnetic field strength conditions, MO Image brightness and clarity had a corresponding change. When it was difficult to avoid the small changes of magnetic field in laser welding, it is necessary to correct seam tracking error in MO image by using appropriate technical means.

In order to acquire better welding quality, the MOI method was applied to track the micro gap weld in real time. In the experiment we regarded the small changes of magnetic field and distance between MO sensor and weldments as noises. A Kalman filter compensated with RBF neural network was used for reducing the noise interference and obtaining high positioning accuracy. For linear dynamic systems, KF is a state minimum variance estimator, which is widely used in the state estimation and the real time machine vision object tracking [17–19]. When the white Gaussian noise statistics and state model can be accurately obtained, the optimal state estimation can be achieved under the least squares condition. However, the welding control system noise and MO sensor measurement noise may be colored noise in real industrial environments [20–22].

Because of optima characteristic of KF gain, KF filter accuracy is high stability. However, the filtering gain is heavily dependent on a priori statistical knowledge of system noise, which is difficult to obtain accurately in actual factory environments. In papers [23–25], authors used an artificial neural networks(ANN) to replace KF gain, and neural network has the ability to estimate the unknown environmental noises. ANN is a simulation of the organizational structure of biological nervous system, with unique self-learning, self-organization, fault-tolerant and highly nonlinear function approximation ability, thus becoming an effective tool for analysis and research of nonlinear system noise [26].

The MOI working principle for weld detection is introduced and the relationship between weld magnetic field distribution and related grayscale image is analyzed. In the process of micro gap weld detection, the inductive magnetic field on the weldment is usually weak, and the information related to weld joint is difficult to obtain in an environment filled with magnetic domain noises and other noises. It is important to reduce the heavy amount of noise affecting the measured signals in the weld MO image. Therefore, under low contrast and strong noise conditions, the weld center state equations