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Magneto-optical imaging deviation model of micro-gap weld joint

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ABSTRACT

Seam tracking is important for butt joint laser welding. A magneto-optical imaging approach is proposed to detect the micro-gap weld whose width is less than 0.2 mm. The symmetry of the magnetic field above the weld joint is an important precondition to ensure the detection accuracy of the magneto-optical imaging method. However, in actual complex industrial scene, it is difficult to guarantee complete symmetry of the magnetic field. This paper proposes an effective method for solving the problem of magneto-optical imaging deviation under an asymmetric magnetic field. Two possible factors causing the asymmetry of magnetic field above weld joint are firstly investigated using finite element analysis. By analyzing the characteristics of the magneto-optic medium used in the sensor and measuring the magnetic field distribution of weld joint at different lift-off height and different excitation voltage, the prediction model of deviation between the weld position detected by magneto-optical imaging and the actual weld position is built by back propagation (BP) neural network. The experimental result of weld seam tracking based on magneto-optical imaging shows that the change of the lift-off height will affect the detection accuracy of the weld position, and sufficient accuracy can be ensured after correcting the deviation according to the prediction model of magneto-optical imaging deviation.

1. Introduction

As one of the most important material processing methods in various industrial fields like automobile, shipbuilding, electronics and steel construction [1,2], laser welding has many advantages such as high precision, automatic processing and the formation of high quality weld with small deformation [3,4]. However, the spot diameter of laser beam must be extremely small for the high energy production. And a micro-gap weld joint (less than 0.2 mm) is required in weld beam tracking of laser welding [5]. Consequently, effective and accurate methods of detecting weld position become more important in adaptive control. One of the most effective methods of non-contact measurement is magneto-optical sensing [6–8]. Recently, magneto optical sensing as a nondestructive testing method has been applied to aircraft rivet site inspection [9,10], leakage flux inspection [11,12] and cracks detection [13,14]. Especially in welding process, magneto-optical sensing has been mainly used in weld seam tracking of laser welding.

For the micro-gap weld whose width is less than 0.2 mm, the weld is almost invisible to the naked eyes, and there are smoke, light, spatter and other interference in the whole welding process. Thus, it is difficult to identify the micro-gap seam and obtain weld seam information using traditional visual sensor in welding process [15]. The magneto-optical sensor is only sensitive to the magnetic field and the noise interference mentioned above has little influence on the magnetic field, thus the approach of weld detection based on magneto-optical imaging is effective for automatic identification and micro-gap weld seam tracking during laser welding. And the comparison of imaging between general camera and magneto-optical sensor is shown in Fig. 1. Also, it is found that the welding speed has little influence on the detection of weld joint position [16]. Theoretically, the weld position detected by magneto-optical sensor is not accurate unless the weld is located on the symmetry plane that above the magnetic field generator. But it is difficult to guarantee the complete symmetry of the magnetic field in the complex industrial scene.

This paper studies the effect of asymmetric magnetic field on magneto-optical imaging of micro-gap weld and presents an approach to predict the deviation between the weld position detected by magneto-optical imaging and the real weld position. A magnetic field measuring system has been applied to obtain the magnetic field distribution above micro-gap weld joint and a magneto-optical imaging system has been applied to capture the magneto-optical images of micro-gap weld joint. The relationship

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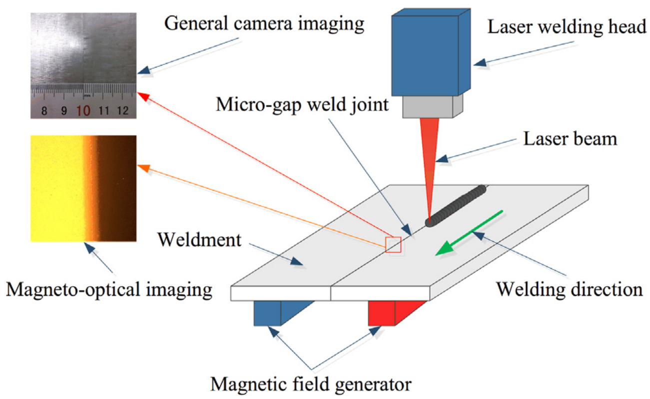

Fig. 1. Comparison of imaging between general camera and magneto-optical sensor.

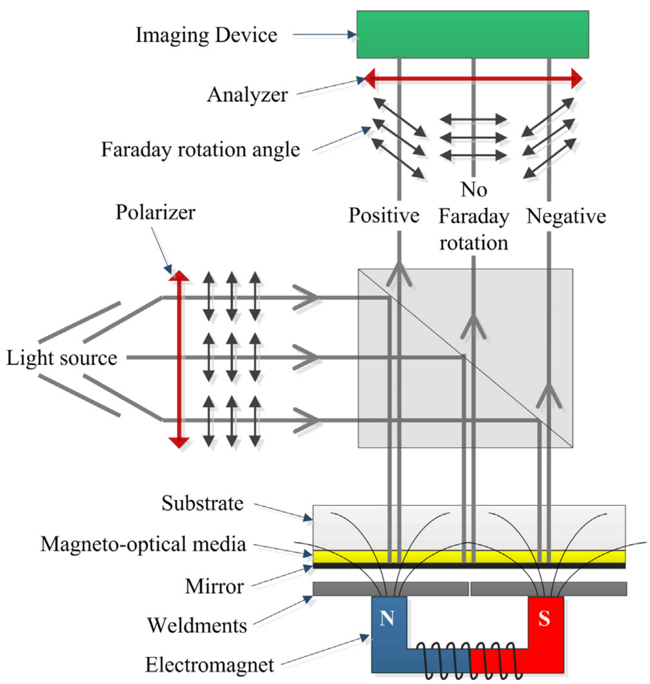

Fig. 2. Schematic of magneto-optical imaging.

between the deviation and the electromagnet excitation voltages, the lift-off height of magneto-optical sensor was investigated.

This paper is organized as follows. Section 2 introduces the mechanism of magneto-optical imaging and shows the experimental system of laser welding based on magnetic field measuring and magneto-optical imaging. Section 3 analyses two different kinds of factors influencing on the weld magnetic field distribution using finite element analysis method. Section 4 presents the weld magneto-optical imaging deviation modeling process. Section 5 validates the deviation prediction model through the experiments of weld seam tracking. Section 6 draws conclusions.

2. Mechanism of magneto-optical imaging and experimental system

The magneto-optical imaging process is show in Fig. 2. The beam light is emitted by light emitting diode (LED) light source and transformed to be polarized light after passing through the polarizer. The Magnetic field is generated by direct-current (DC) electromagnet. The weldments is setup above the electromagnet and magnetized in the magnetic field. The magneto-optic medium is setup above the magnetized weldments. According to Faraday magneto-optical effect [17,18], the Faraday rotation angle of polarized light will be changed when the polarized light goes through magneto-optic medium in the magnetic field. The Faraday rotation angle is related to the magnetic field present in the magneto-optical medium and can be figured as follow:

$$\theta = VBL \tag{1}$$

where θ is the Faraday rotation angle of polarized light(in radians), V represents the Verdet constant(in units of radians per tesla per meter), B represents the magnetic induction intensity(in teslas) in the light direction and L represents the distance(in meters) that the polarized light goes through in the magneto optic medium. The Faraday rotation angle will be positive or negative if the magnetic field is generated by magnetic pole with different magnetism (north or south). The polarized light whose polarization has been altered is detected by analyzer, thus the imaging device can capture corresponding magneto-optical images. As analyzed before, it is aware that the magneto-optical image generated in the imaging device contains the magnetic field distribution of micro-gap weld joint.

The experiment was performed by using a laser welding system based on magneto-optical imaging which is shown in Fig. 3. The electromagnet whose magnetic field intensity is controlled by DC power supply was set up on the top of moving table. The weldments was magnetized by the electromagnet below. The magneto-optical sensor was set up over the weldment in the welding direction. The magneto-optical image sequence was captured by the magneto-optical image acquisition and transferred to the monitoring computer, where the image processing and feature extraction were performed. The hall sensor was put on the top of the weld joint in order to get the magnetic field distribution and the magnetic induction intensity was performed on the teslameter. The weldment (low carbon steel Type Q235) was driven by a stepper motor and the welding speed was 4 mm/s. The frame rate of magneto-optical sensor was 25 fps and image resolution was 512 pixel × 512 pixel.

3. Finite element analysis of weld magnetic field

In order to figure out the influence of asymmetric magnetic field on magneto-optical imaging, the reason that makes the magnetic field asymmetric should be analyzed first. Consequently, two presumptions were proposed, one presumption was different weld position on the U-shaped electromagnet that make the magnetic field distribution above weld joint changed, another presumption was different magnet shape of U-shaped electromagnet that make the magnetic field distribution above weld joint changed. By simulating the two guesses using finite element analysis which is shown in Fig. 4 and Fig. 5, where *wp* represents the horizontal distance between weld position and axisymmetric center of the magnet and *ms* represents the difference of right magnetic pole width and left magnetic pole width, the guesses could be verified. The color scale of simulation result indicates the magnetic induction intensity. It is unsuccessful welding that the deviation between laser beam focus spot and seam center is over 1 mm during seam tracking of laser welding. Therefore, the deviation range of seam center from −2 m to 2 mm was studied in the FEM model to analyze asymmetric center. However, the parameter of magnet shape in the finite element model of asymmetric magnet depends on the actual magnet shape which was used in the experiments. Since the actual width of one magnet pole is 10 mm, the difference value of magnet width was chosen as the range from zero to −6 mm.

Maxwell's equations is the theoretical basis of electromagnetic field analysis, the differential form of Maxwell's equations is given by Eqs. (2)–(5), where H is the magnetic field intensity, B is the magnetic induction intensity, E is the electric field intensity, D is