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Modeling for detecting micro-gap weld based on magneto-optical imaging

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ABSTRACT

A new method based on Faraday magneto-optical effect to detect micro-gap weld whose width is less than 0.1 mm in a butt joint laser welding is developed. The characteristics of magneto-optical images and magnetic field distribution reflecting the weld position are analyzed. An electromagnet exciter is adopted to magnetize the carbon steel weldment and establish a leakage magnetic field at the welding joint. Magneto-optical sensor is set over the magnetized weldment to obtain the magneto-optical images. A model based on the magnetic charge theory is proposed to investigate the magnetic field distribution over the welding joint and it is demonstrated by computer simulations and experiments, which show that the midline of welding joint is corresponding to the transitional zone midline in a magnetic-optical image. This model is evaluated by seam tracking experiment and shows that it can effectively and accurately track the micro-gap weld.

1. Introduction

Welding is a fundamental and important process in manufacturing [1–3]. Laser welding technology has become a significant technique as it has advantage of high density, great depth-to-width ratio and tiny heat affected zone [4–6]. During laser welding, it is essential to focus laser beam spot on the weld center and track its path [7–9]. Therefore the first key issue is the real-time accurate detection of actual weld position. At present, structured light method is regarded as a relatively mature detection technology in laser welding seam tracking. It employs the strip-type structured light (in the visible spectrum of laser) to scan the weld seam. The shape of strip-type light will be altered if the weld has groove or gap and its shape is changed. A camera which suits for the light is adopted to capture the altered strip-type light, using trigonometric survey principle and image processing to locate the welding seam. However, this method has an insurmountable shortcoming that it is difficult to recognize or track the weld when the gap width of tight butt weld is less than 0.1 mm. As using an ordinary camera to capture the micro gap weld, the deformation of strip-type light is rather small, meanwhile the image gray value of weld during laser welding with much light radiation and spatters changes so small that it is difficult to identify the position of micro gap weld.

The magneto-optical (MO) detecting technique is usually being used in the large tested skin layer and subsurface stratum of the airframe's aluminum elements, as well as the flaw by corrosion and the fatigue cracks near rivets in the steel and titanium alloy constructions [10–12]. It also has been certified that MO imaging technology could be used in identifying detection and tracking micro gap weld [13–15]. Researches on weld detection show that the centerline of MO transitional zone is the midline of the welding gap, without giving the detailed descriptions. Consequently it is necessary to investigate the distribution of magnetic field corresponded with the welding gap.

This paper aims to analyze the distribution of magnetic field on the micro-gap weld. A MO image sensor is set up to obtain the information of the micro gap weld according to Faraday MO rotation effect. An electromagnet establishes a magnetic field on the weldment. When the polarized light of MO sensor propagates through the medium of MO sensor, its polarization orientation will rotate to a certain angle due to external magnetic field. This light which contains the weld information passes through an analyzer to a CMOS camera and forms a MO image. A recognition model is adopted to locate the butt weld, and the feature of MO imaging mechanism is studied. Seam tracking is performed to evaluate the proposed model. As MO imaging is reflected by magnetic field instead of

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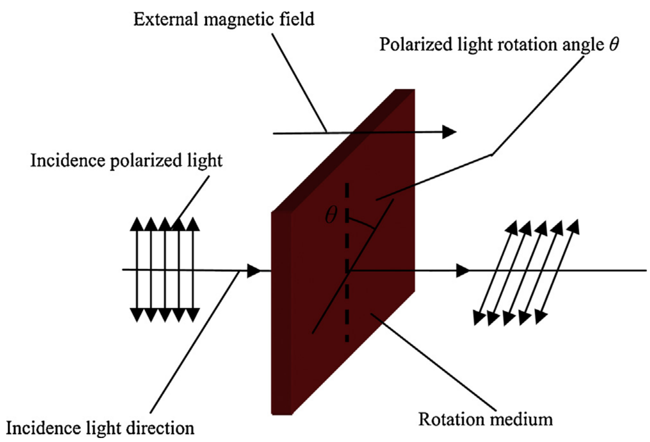

Fig. 1. Diagram of Faraday MO effect.

visible light, hence MO sensor is hardly disturbed by spatters, radiation of light-induced plasma or other optical radiations in laser welding. This paper proposes a magnetic distribution model of butt joint weld according to the magnetic charge theory. Through computer simulation and actual measurement contrastive analysis, it confirms the effectiveness of the model and enhances the precision of recognition of micro gap weld and seam tracking.

2. Weld detection based on MO imaging

2.1. MO rotation effect

When a beam of linearly polarized light propagates through an optical rotation medium, if an external magnetic field is added in the direction of the propagation of MO medium, the vibration plane of light will rotate an angle θ. This phenomenon is called Faraday effect or magnetic rotation effect, which is shown in Fig. 1. The angle of rotation θ mainly depends on the light wavelength, the intensity of external magnetic fields and the propagation distance through medium. Angle θ can be described by [16]

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

where B is the external magnetic flux density, L is the optical path which the light propagates through the medium, V is the Verdet constant.

2.2. Weld detection system based on MO sensor

The structure of laser welding system is shown in Fig. 2. The weldment is moved at speed of V, as a magnetic exciter is fixed below weldment. A MO imaging sensor is placed over the weld, taking a MO image that reflects the weld position while the weldment is magnetized by the magnetic exciter.

2.3. Working principle of MO imaging sensor

Fig. 3 shows the schematic diagram of MO imaging sensor. When the light from LED propagates through a polarizer, it will be linearly polarized. The light propagates through a MO medium and is reflected, which contains the surface information under the medium. Meanwhile there is a leakage magnetic field over the weld which parallels the propagation direction of the light. This causes the magnetic effect and leads to rotation of polarization direction of the light. Therefore the polarized light may carry information of weld and propagate through an analyzer, finally being detected by a CMOS camera and realized by real time imaging detection algorithm.

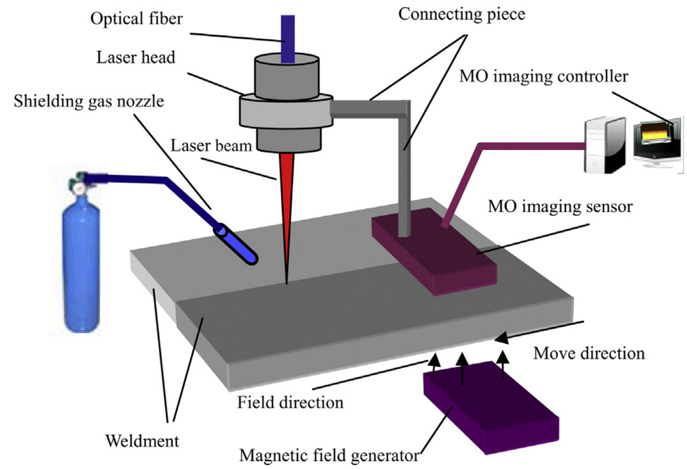

Fig. 2. Micro gap weld detection system.

3. Magnetic field modeling of micro gap weld

3.1. Magnetic circuit distribution of weldment

Weldment is magnetized and mainly produces two magnetic fields Φ_1 and Φ_2 in environment of the external electromagnetic fields, which is shown in Fig. 4. The magnetic field Φ_1 is generated on the weldment through magnetic induction by external electromagnet. As the magnetic flux mainly flows along the magnetic circuit through the weldment, the MO imaging sensor is usually placed about 1 or 2 mm high above a butt joint weld. The intensity

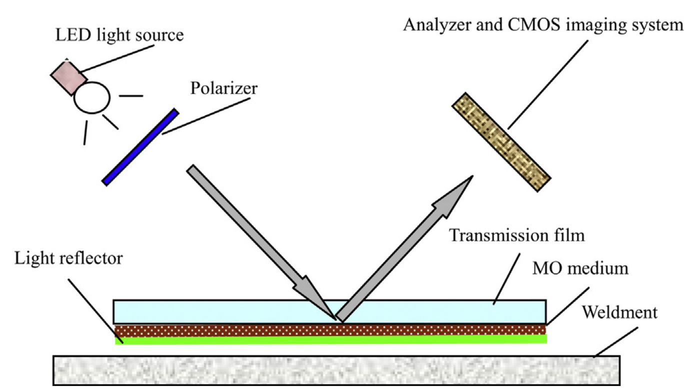

Fig. 3. Structure diagram of magneto-optical sensor.

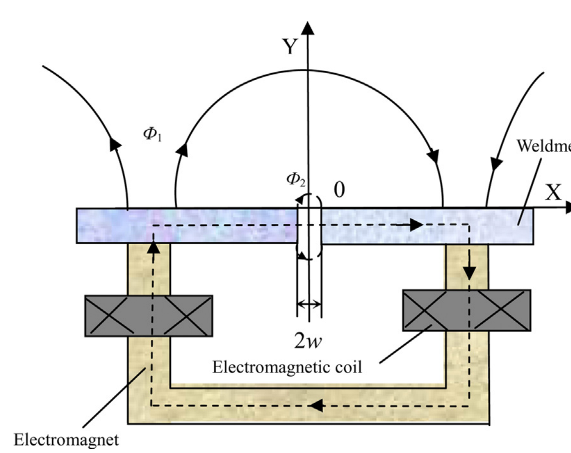

Fig. 4. Weldment and magnetic circuit distribution.