Extraction of Weld Pool Feature Based on Visual Sensing during High-power Fiber Laser Welding

Ziqin Chen[a], Xiangdong Gao[b,]* and Qian Wen[b]

School of Electromechanical Engineering, Guangdong University of Technology, Guangzhou, Guangdong Province 510006, China

[a]kuaileziqin@sina.com, [b]gaoxd666@126.com, *Corresponding author

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Abstract. In the process of the high-power fiber laser welding, the weld pool feature is related to welding quality. Here, a near infrared image acquisition system was used to acquire the weld pool information. After acquiring the weld pool regional image, the methods such as filtering image denoising, image enhancement, morphological processing and image segmentation were applied to analyze the weld pool feature information. It offered a reliable visual information method for monitoring of welding quality.

Introduction

Compared with the traditional welding, the high-power laser welding has the advantages of high welding speed, little welding heat affect zone and big depth-width ratio. It can concentrate energy and obtain the welding between metal and metal or non-metallic material. In the process of automatic welding, sensing and controlling of welding information is the key and difficult points [1]. Real-time monitoring the shape of the weld pool is the key to get a good weld. Meanwhile, weld pool image sensing is the most important part of welding sensing. The information obtained from the weld pool enables us to make the judgment as follows: 1) the quality of the welding; 2) shape of the welding line; 3) the defects of the welding appearance. Furthermore, the information still enables us to track and identify the welding line in the process of welding.

The size, shape and dynamic changes are the main reasons which affect the welding quality and appearance. Here, the experiments of the high-power fiber laser deep penetration welding on the stainless steel plates were carried out. Due to the large heat, keyhole phenomenon occurred in the preceding of weld pool. During the laser welding, the geometry parameters of keyhole were the key point to influence the quality of welding. In order to improve the welding quality, it was an effective measure to study the changing process of weld pool [2]. The high-power fiber laser weld pool images were captured by a near-infrared high speed camera, and these images were analyzed. Experimental results showed that the weld pool features could be extracted by using proposed methods.

Weld pool image acquisition device

The experimental setup included IPG Photonics Corporation YLR-10000 laser welding equipment, a six-joint Panasonic VR-016 type robot, protect cylinders and a welding table. The welding table consisted of a NAC Memrecam fx RX6 high-speed camera, precise servo motors and fixtures. A near-infrared narrowband optical filter (spectral ranges 960-990nm) was used to eliminate radiations of plume and spatter interference and accessed to the best thermal imaging. The high-power fiber laser welding device is shown in Figure 1.

Test material selection: the thickness 10mm Type 304 stainless steel plates, dimensions of 150mm×49mm×10mm, were used as the specimen. Clamped by the fit-up, the gap between the two plates was no more than 0.1mm. According to the deviations in the actual production, the weld path used the way of butt joint welding. The movement path of the laser beam was a diagonal line, i.e. the laser beam deviated from the weld centerline at first, then gradually aligns and then deviated again. In this way, we could observe and analyze the changes of temperature distribution and heat radiation characteristics caused by the laser beam align and deviation from the weld centerline. During the entire experiments, the laser weld path was 118mm, totally 3150 frame infrared thermal images were collected, including the laser beam align and deviation of the weld centerline. High-power fiber laser welding test conditions are listed in Table 1.

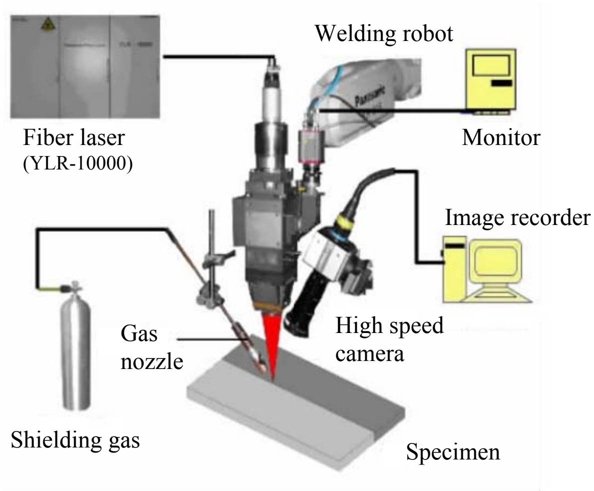


Fig. 1 High-power fiber laser welding experimental device

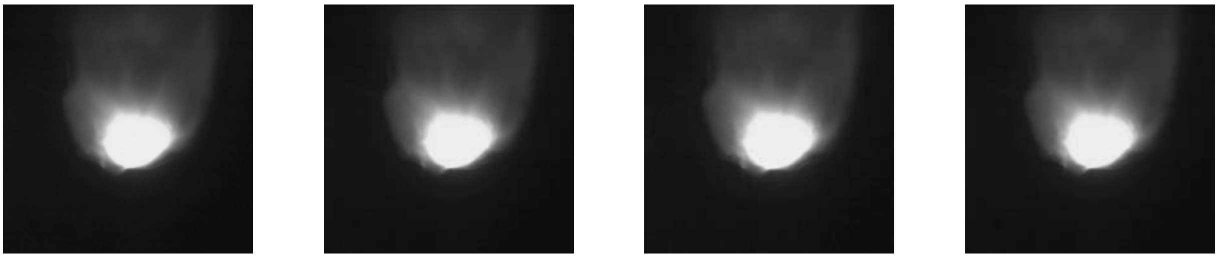
Table 1 Fiber laser welding conditions

Laser power	Beam diameter	Welding speed	Shielding gas	Gas flow	Mount angle of camera
10kW	200μm	2.5m/min	Ar	20L/min	15°

Weld pool image acquisition and processing

Theoretically, the process of weld is a complex phenomenon which involved heat transfer, material metallurgy, solid and fluid mechanics. According to Stephen-Boer Mann law, infrared radiation of the total energy M and the thermodynamic temperature T are proportional to the fourth power. Great changes happened in the total energy of the infrared radiation while temperature changed little. Correspondingly, morphological changes occurred in the infrared thermal imaging. This spectral of near-infrared imaging ranges of 960-990nm, with high-speed camera speed of 1000f/s, could capture the image size of 512piexel×512 pixel . An original image of weld poor is shown in Figure 2(a).

As noises existed in the original image, filter denoising was applied. To depress the noises with airspace, the methods of median filter, order statistics filtering and wiener filtering were used [3]. The image processing is shown in Fig. 2.

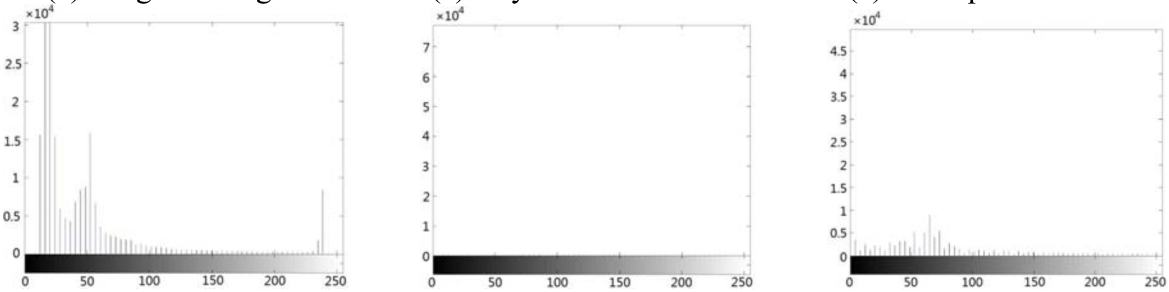


(a) Original image (b) Median filter (c) Order statistics filter (d) Wiener filter

Fig. 2 Weld pool image filtering

It can be seen that the wiener filtered image could show weld pool, keyhole and background more clearly. Keyhole zone, as the effect of laser beam spot usually has the highest temperature. In infrared thermal imaging, high and low temperature is shown by the level of gray levels. The higher the temperature is the greater the gray level is. In order to distinguish the weld pool, the keyhole and the background, and extract the accurate parameters of the weld pool and keyhole, it was necessary to contrast enhancement the filtered weld pool image. The images after enhancement and the histogram are shown in Fig. 3.

(a) Original image (c) Keyhole enhancement (e) Weld pool enhancement

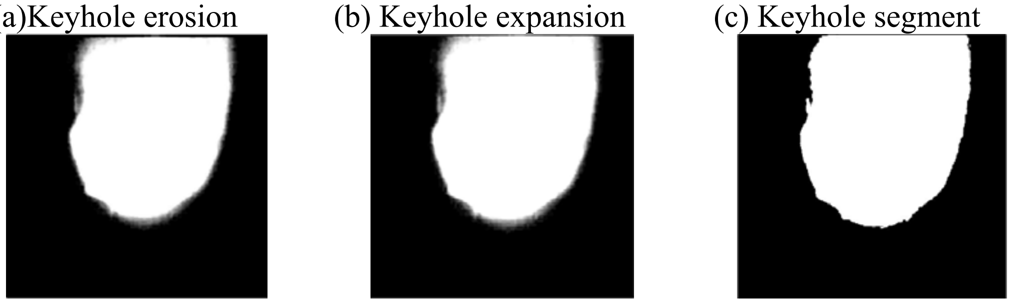


(b) Original histogram (d) Keyhole histogram (f) Weld pool histogram

Fig. 3 Contrast enhancement images of weld pool and their histogram images

Measuring and extracting the corresponding shape of the thermal image, so as to analyze and distinguish the image, and then undertook mathematical morphology operation. It included the erosion, dilation, opening and closing operation. Choosing the suitable structure element can help to remove the isolated areas and burr in the image [4]. Morphology processed image is shown in Fig. 4. In order to extract effective image from infrared thermal image, image segmentation was needed. Segmented image is also shown in Fig. 4.

(a)Keyhole erosion (b) Keyhole expansion (c) Keyhole segment



(d)Weld pool erosion (e) Weld pool expansion (f) Weld pool segment

Fig. 4 Opening operation and segmentation of weld pool images

Image feature extraction

Weld pool images contained the image characteristics and keyhole characteristics. In order to study the influence of dynamic changes on the weld quality in the process of welding, the characteristic parameters were defined: keyhole width, keyhole area, keyhole left, right, up and down endpoint coordinates [5]. Keyhole characteristic parameters are shown in Fig. 5 and Table 2.

(a) Keyhole parameters (b) Weld pool parameters

Fig. 5 Characteristic parameters of keyhole and weld pool

Table 2 Characteristic parameters of keyhole and weld pool

(a) Characteristic parameters of keyhole (unit: pixel)

Area S1	Width L1	Left endpoint	Right endpoint	Up endpoint	Down endpoint
5.1343e+05	189	(524,472)	(732,456)	(579,384)	(594,546)

(b) Characteristic parameters of weld pool

Area S2 (pixel)	Width L2 (pixel)	Half-length h/2 (pixel)
8.5812e+05	376	302

Conclusion

According to the characteristics of high-power fiber laser butt joint welding, the weld pool information monitoring system was designed. It could eliminate the interference of the plume and spatter, and obtain clear weld pool images. Weld pool configuration is an important factor affecting the quality of welding. By filtering the image denoising, image enhancement, morphological processing, and image segmentation, it could obtain the weld pool image feature information.

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References

[1] L. Mo and X.D. Gao: Modern Welding. Vol. 100 (2011), p. J-20.
[2] X.D. Gao and Y. Zhang: Transactions of the china welding institution. Vol. 32(2011), p. 14.
[3] R.C. Gonzalez and R.E Woods: *Digital Image Processing, Third Edition* (Publishing House of Electronics Industry, China, 2011).
[4] Q. Zhang, J. Zhan and S. Chen: *Detailed matlab function image and its application* (Publishing House of Electronics Industry, China, 2011).
[5] X.D. Hu and C.H. Dong: *Matlab from entry to the master* (Publishing House of Posts & Telecom Press, China, 2010).