Development of image processing system for innovative laser welding of nuclear fuel assembly

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1. Introduction

Laser welding technique has been rapidly developed with respect to high power lasers such as CO_2 laser, Nd:YAG laser, and etc. Laser welding has advantages to weld materials more precisely due to precise focusing of the laser beam and a little heat affected zone(HAZ)[1]. Nowadays, Nd:YAG lasers are used for manufacturing space grid assembly of nuclear fuel[2]. The correct positioning is very important factor in laser welding of space grid. We have developed an image processing system and optical assembly for correcting weld positions of space grid assembly in laser welding process. In this paper, the development of optical design and image processing system for a new innovative laser welding system is described.

2. Instrumentation and Experiments

In this section, the optical design for acquiring the space grid image and the digital image processing system for precise correcting the welding position, were described.

2.1 Optical System Design

The optical system for the digital image processing of the space grid laser welding system is shown in Fig. 1. The Dichroic mirror is a kind of Hot mirror that reflect only IR laser beam and transmit visible light. L1 and L2 are relay lenses which deliver the image of space grid to CCD camera. L3 is imaging lens of the CCD camera. The optical system is designed and analyzed using ray-tracing S/W(Zemax Engineering 8.0). The imaging optical system has 4 groups of optics assembly. The most important factor of the optical system is distortion. This optical system was optimized so that the distortion was less than 0.2 %. Fig. 2 shows the 3rd order aberration of the optical system (field curvature and distortion).

The CCD camera has 1392x1040 pixels and IEEE1394 interface, which can acquire images at 15 Hz. The field of view of the optical system is 35 mm x 48 mm. The pixel resolution of the digital image processing system can be 35/2 um, and the positioning error could be corrected less than 20 um resolution by this image feedback system.

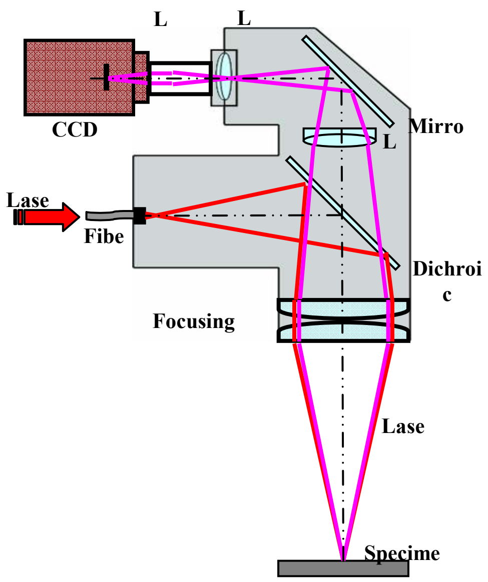

Fig. 1. Layout of the Optical system of laser welding head assembly for Digital Image Processing

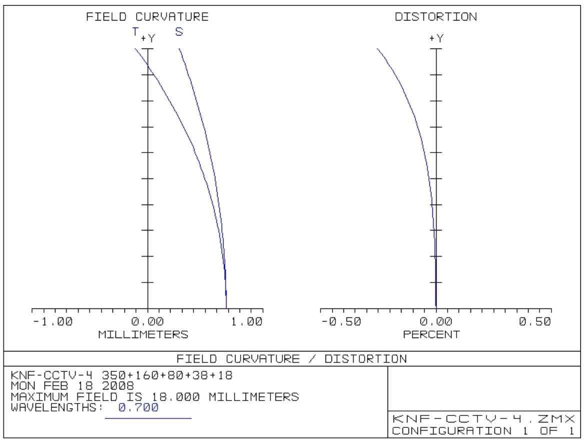

Fig. 2. 3rd order Aberrations of the optical system. The distortion aberration is less than 0.2 %.

2.2 Digital Image Processing System

The digital image processing system deals with the image, acquired from the camera embedded in welding head assembly. The output is the relative position errors to the current position and its four neighbor positions. This is carried out by the simple automatic thresholding method followed by area analysis to find the center of gravity robust to noise. Fig. 3 shows the flow chart of the proposed image processing algorithm.

A commonly used thresholding technique, is used to get satisfactory results for thresholding the input image with a histogram of bimodal distribution[3]. And FFT based methods also can be used[4]. Next, blob analysis which consists of a series of processing operations is used to eliminate blobs that are of no interest based on their spatial characteristics, and keep only the relevant blob for further analysis. Then finally the center position is extracted by center of gravity from only the remaining region for correcting positioning error as shown in red box of Fig 4.

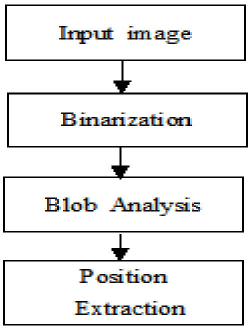

Fig. 3. Flow chart of the proposed image processing algorithm

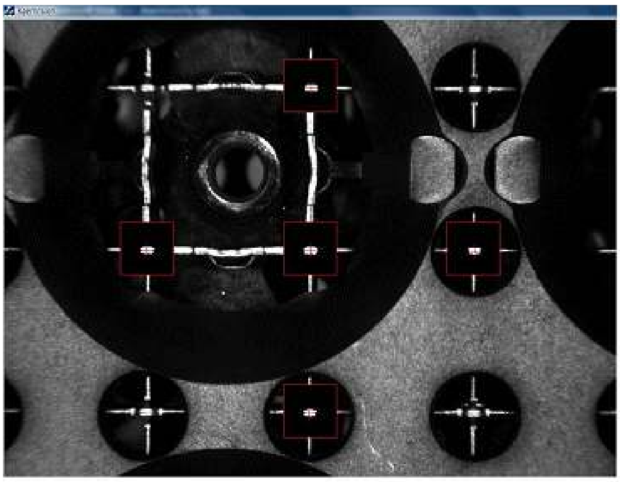

Fig. 4. Captured image and its result processed in red box

2.3 Laser Welding Experiments

A laser welding system is implemented using a pulsed Nd:YAG laser and 3-axes CNC stages. The laser beam is delivered by a optical fiber of which core diameter is 600um. Some welding experiments were carried out using the laser welding system with digital image processing system for reducing positioning errors. The pulsed width of the laser 6 ms, the repetition rate of the laser beam is 64 Hz, and the average power of the laser is about 200W. The spot diameter of the laser beam at the space grid sample is 1.3mm. Fig. 5 is the Photograph of the welded area of the space grid assembly. The size of the molten pool of the welded area is 2.2mm diameter.

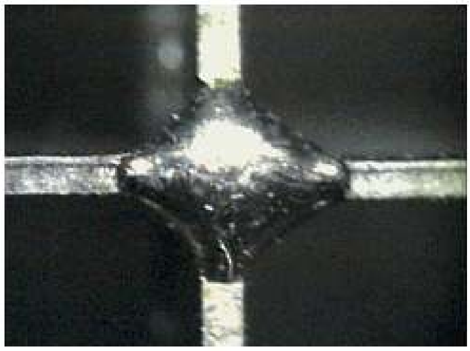

Fig. 5. Photo of the Welding area of the space grid assembly. The width of the grid is 0.46mm, and the positioning error is less than 20um.

3. Conclusions

In conclusion, we have developed an optical system and image processing system for a new innovative laser welding system for manufacturing space grid assembly of nuclear fuel, which corrected the positioning error by feedback process. The distortion aberration of the optical system is optimized by ray-tracing method and is less than 0.2 % through full field of view. The image processing program is developed to correct positioning error of the space grid during laser welding. The resolution of the feedback position correcting system of the space grid assembly is less than 20 um at sub-pixel resolution. Using the image processing system, some laser welding experiments were carried out in order to test the performance of the system.

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