Research and application of laser splicing welding equipment for doorings based on intelligent vision splicing system

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Laser welding is an advanced welding technology that combines sheets of different thicknesses, materials and coatings through the laser welding process. In the manufacture of hot stamped body door rings, laser splicing technology can realize lightweight design, improve body performance and reduce cost. The fully-automatic intelligent visual splicing system applied to laser splicing welding adopts the latest high-precision visual positioning technology and plate intelligent splicing technology to realize the fully-automatic and high-precision splicing of multi-piece door rings. The research and application of this system is of great significance for realizing the full automation of hot stamping laser welding door ring parts, improving the quality and stability of welding, realizing the lightweight design of car body and reducing the production cost.

Keywords: Lightweight body; Laser welding; Hot stamping; Car body dooring; Visual guidance.

1. Introduction

Under the environment of increasingly stringent requirements for vehicle environmental protection and safety, it promotes the development of body design in the direction of lightweight selection of materials and structural integration, which is more representative, such as the large-scale application of hot stamping steel, one-piece die-casting base plate assembly and one-piece laser splicing welding hot molding door ring technology.

The traditional door ring is the body of the A-pillar, A-pillar side beams, B-pillar, B-pillar plate, door sill plate and other parts of the car molded separately, and then through the riveting or spot-welding technology to connect them together. The so-called one-piece laser splicing and welding hot stamping door ring, that is, several of the above parts are welded together by laser splicing and welding, and then stamped and molded at one time [1]. Compared to conventional door rings, one-piece door rings with thermoforming technology can reduce weight by about 20%, and the side and frontal crash results are also greatly improved.

The Multi-Piece Thermoforming Door Ring Laser Splicing and Welding Machine is a laser processing machine specially developed for the automated production of one-piece thermoforming door rings. By adopting the latest high-precision visual positioning technology, plate intelligent splicing technology, and aluminum-silicon coated plate welding technology, the equipment can realize the fully automatic welding of single and double door rings of the body.

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2. Laser welding principle and engineering application

The main principle of laser splicing welding is to use a high energy density laser beam to produce localized melting in the welding area to weld two or more metal materials together [2]. Laser welding has the advantages of fast welding speed, high weld quality, low energy consumption, no pollution, etc., which can effectively improve the collision resistance of the body, reduce the weight of the body, reduce the cost of vehicle construction and fuel consumption, and simplify the assembly process. The principle of laser fillet welding is shown in Fig. 1.

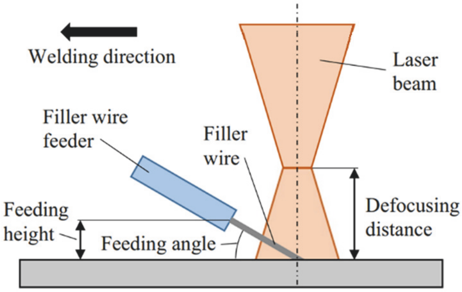


Fig. 1. Principal diagram of laser filler welding

3. Key technology research of laser welding equipment

3.1. *Layout of the whole line and functional control area*

The plane layout of the laser welding production line is shown in Fig. 2. It first consists of pre-positioning loading area, precise positioning loading area and intelligent visual splicing area to form the blank positioning and splicing functional area for positioning and splicing of door ring plate materials. The precisely positioned and spliced blanks enter the welding area and are welded by the trajectory movement of the single laser welding head or the double laser welding head. Among them, after pre-positioning is realized by mechanical motion control, the spliced parts are visually inspected and the splicing gap is adjusted under the guidance of the intelligent vision system to meet the requirements of the welding process. After completing the welding, the spliced weld plate enters the quality inspection area, and through the weld inspection instrument, it is determined whether the welding quality of the spliced weld plate meets the inspection standard [3]. According to the results and judgment of quality inspection, in the discharging area, qualified products are placed in the qualified product area (stacking), and unqualified products are pushed to the unqualified area for manual processing, as shown in Fig. 3.

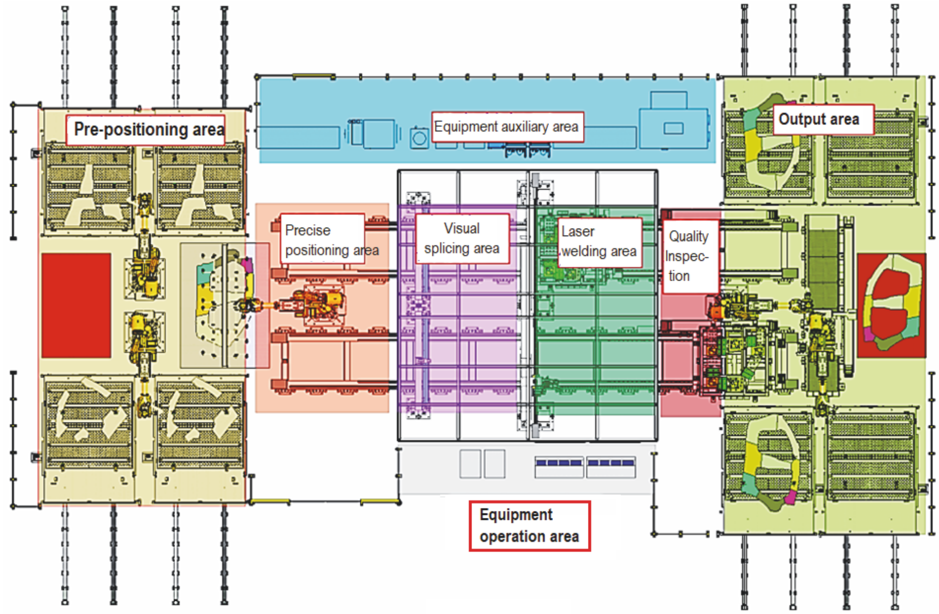


Fig. 2. Functional control area of the laser welding line

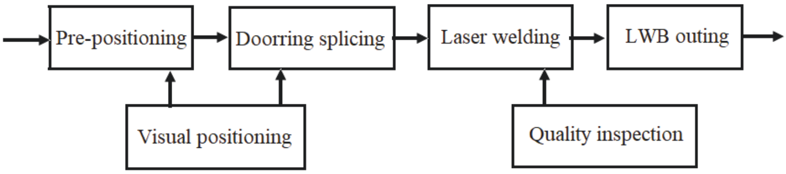
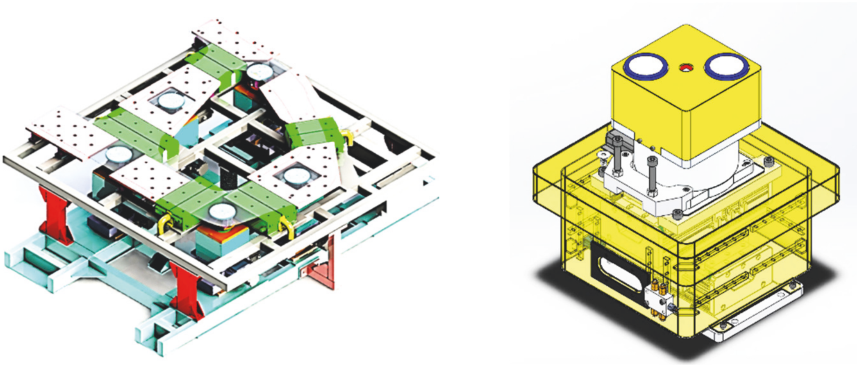


Fig. 3. Flow of the process and monitoring of the laser welding line

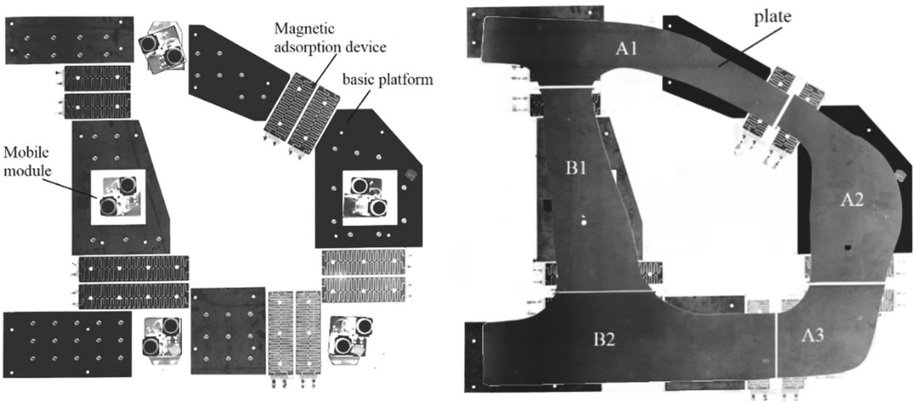
3.2. *Intelligent visual guidance splicing method*

Intelligent visual splicing system consists of two parts, visual guidance system and intelligent splicing tooling. Among them, the vision guidance system takes high-precision line array camera and built-in intelligent algorithm as the core, which can realize the quality inspection of the outer contour of the workpiece, splicing path and attitude planning and other functions. Multi-splicing intelligent splicing tooling, with multiple sets of motion modules as the core, completes the splicing of the door ring according to the motion path and attitude of the workpiece planned by the vision guidance system.

After obtaining image and position information through camera scanning, it compares with the set position information of billet weld to obtain the target error. After the error is fed back to the PLC, the system automatically operates the moving module that carries the billet to do planar movement or rotation to eliminate the error between the monitoring data and the set data, iterating repeatedly until the error is within the set threshold. Fig. 4(a) shows the plan view of the multi-splicing intelligent splicing tooling, and there is a motion module under each splicing plate, which can drive each splicing piece to realize the horizontal motion in the XY direction, and the rotary motion around the C-axis, as shown in Fig. 4(b).



(a) General schematic diagram of the tooling (b) Schematic diagram of the motion module
Fig. 4. Intelligent splicing tooling



(a) Intelligent splicing tooling structure (b) Photo of the completed spliced sheets
Fig. 5. Intelligent splicing tooling and door ring photo.

Adopting intelligent vision splicing system, through intelligent algorithms, according to the actual size of each piece of sheet material, unified calculation of splicing attitude, splicing gap can be arbitrarily set according to the process needs, to improve the qualification rate of the parts and production efficiency, and greatly reduce the cost of manual operation.

Taking a typical door ring as an example, each weld seam adjustment area is arranged with magnetic suction cups and moving (slewing) module components, as shown in Fig. 5(a). After the sheet is placed in the corresponding position, the precise positioning operation is first carried out by the vision system, and then the attitude change and movement path from the initial position to the splicing position of each piece is determined by the intelligent algorithm, and finally the sheet moves to the end position driven by the movement module. After the plate is in place, the magnetic suction cup suctions and locks the position of the spliced welded plate, as shown in Fig. 5(b). The decision criterion inside the intelligent algorithm ensures that the width of the spliced seam of the completed plate is uniform and the deviation of the parallelism of the spliced edge is minimized.

4. Intelligent algorithms based on vision-guided monitoring

4.1. *Acquisition of visual original design model and monitoring model*

The hardware of the vision monitoring and control system consists of a linear scanning camera, camera optics and a dedicated light source. The pre-designed model of the position of the spliced welded plate is shown in Fig. 6. The contour of the plate in the project of the splicing adjustment, and the contour of the weld gap, as shown in Fig. 7. When the position information of the two completely overlap, the magnetic suction cup can be operated to lock the position of the blank.

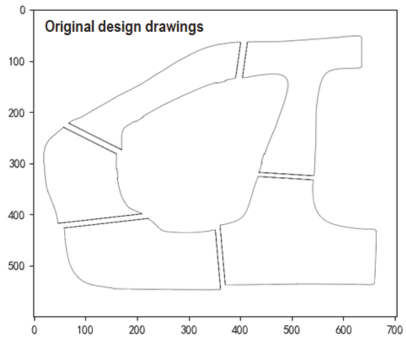


Fig. 6. Spliced weld plate splicing original design model

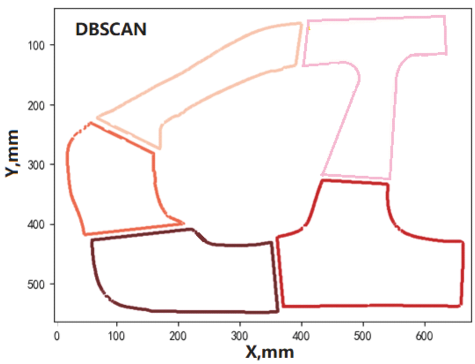


Fig. 7. Error obtained by comparing the reconstructed model with the original design model according to visual monitoring

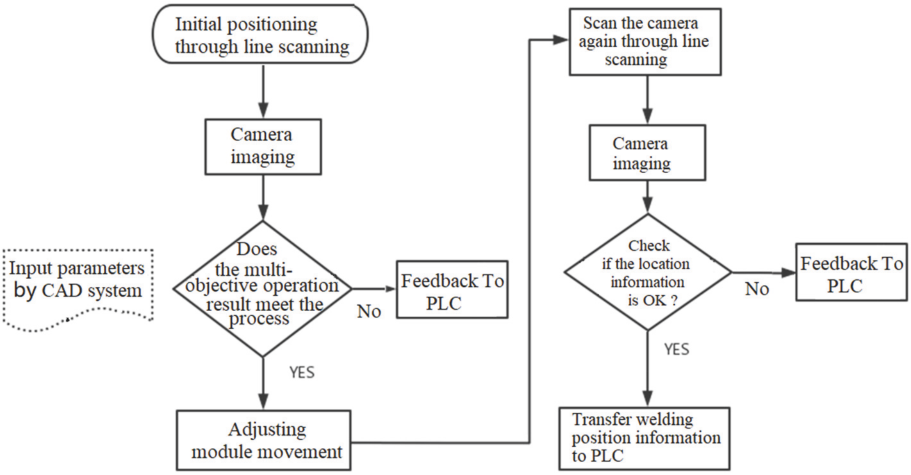


Fig. 8. Visual monitoring and splicing guidance control system

The blank is moved and rotated, executed, and the control adjustment process of the whole process is shown in Fig. 8, which gives the control adjustment process of the blank image detection data and the position data of the set model.

4.2. *Optimization algorithms*

In this paper, two multi-stage optimization algorithms are used to illustrate the impact of the algorithms of image processing for visual monitoring on the efficiency and accuracy of the control of the splicing actuator [4]. The vertex coordinates of the two straight lines of each block to be spliced, calculated below, are obtained from image acquisition.

4.2.1. *Rotation optimization + translation compensation algorithm (Algorithm 1)*

(1) Establish the objective function

$$f(\theta) = \sum|\theta i| \quad \text{, Here are i=1,2,……,n} \tag{1}$$

(2) Establishing linear constraints and nonlinear constraints, the

$$s.t.\begin{cases} dlow_{limit} \leq D(sement\{i\}, segment\{j\}) \leq dup_{limit} \\ \theta_2 \leq \theta \leq \theta_1 \\ \cdots\cdots \end{cases} \tag{2}$$

(3) Optimization solving to obtain the optimized minimum value and the angle of rotation of each block.

$$\theta i, i = 1,2, \dots \dots, n. \tag{3}$$

(4) Calculate the distance between each block according to the rotation angle, and calculate the distance between each plate. Can be decomposed into the corresponding plate affine coordinate system axes to be adjusted to the weld distance.

(5) Experiments have shown that, in general, only along the first board two sides of the affine coordinate system composed of the first board and its neighboring distances can be shifted.

4.2.2. *multi-stage heuristic optimization (Algorithm 2)*

(1) Establish the objective function
The objective function for coordinates x,y and turning angle θ, see Eq(4).

$$f(x, y, \theta) = \sum distacne(segmenti, segmentj) \tag{4}$$

(2) Constraints

$$s.t.\begin{cases} dlow_{limit} \leq D(sement\{i\}, segment\{j\}) \leq dup_{limit} \\ \theta_2 \leq \theta \leq \theta_1 \\ \dots\dots \end{cases} \tag{5}$$

(3) In the first stage (splicing algorithm), the center alignment is achieved by splicing the other blocks first.

(4) In the second stage, compensate with n-block transformation

Fixed plate 1, move the nth plate, consider the gradient of X + weld distance Y in the direction of the wrong seam, where X is a function of translation (x,y), and the weld distance is a function of the direction of the fastest distance reduction (a combination of rotational and translational judgment of who changes the most to choose, is a function of the rotational θ and translational). The nth block is used to make up the misalignment and weld distance between the first block and the nth block until the distance constraint between the nth block and the n-1th block is satisfied or reached.

(5) In the third stage, the n-1 block is used to compensate the distance between the n block and the n-1 block.If all the above requirements are satisfied, it is finished. Otherwise, the distance between block n-1 and block n is changed as a whole and the distance between block n-2 and block n-1 is changed. Until the distance constraint between block n-1 and block n-2 is satisfied or reached.

(6) Calculate the test until the condition is satisfied or the need to change the first block is reached. After completing a cycle of testing, end the calculation and exit the calculation process.

The two algorithms mentioned in this paper are done in stages to control the operation scale and reduce the computational complexity.

1) Based on the example of the implementation of the separation of 1 board while the others are not separated, Algorithm 1 Rotation Optimization + Translation Compensation is used to give an optimal solution of the small-angle transformations; secondly, the other cases of the pictures that are completely separated or partially separated are equivalent to the case of the separation of the 1 block (aligning the other modules first, and finally dealing with the Secondly, other cases of completely or partially separated pictures are equivalent to the case of 1-block separation (first align other modules, and finally deal with the distance between the nth block and the 1st block), and the experiment verifies the feasibility of the idea.

2) Algorithm 2 basically realizes the experiment of judging the convergence to the ideal region based on the distance, and it is still to be fully realized according to the design of the algorithm. The algorithm is equivalent to simplifying the outermost layer to a gradient about the direction of the wrong seam in the direction of the seam distance, and then using the class gradient descent method to solve. Considering that both directions are composite functions with respect to translations, there may be inconsistencies in the direction of the mis-seam and in the direction of the seam distance, which need to be resolved in detail by a further strategy.

5. Conclusion

This study focuses on the research and application of laser splicing welding equipment for door rings based on intelligent vision splicing system. Laser splicing technology achieves the goals of lightweight body design, improved body performance and cost reduction by combining panels of different thicknesses, materials and coatings. The application of intelligent visual splicing system in the laser weld blanks process can improve the welding quality and productivity, reduce the labor cost, and is of great significance for the intelligentization of Laser weld blanks production line.

By studying the principles and engineering applications of laser splicing technology, the authors demonstrate its importance and advantages in body manufacturing, and provide new ideas and technical support for lightweight body design. The fully automatic vision-guided splicing method is thoroughly studied, and the functions of workpiece outer contour quality detection and splicing path planning are realized by high-precision line-array cameras and intelligent algorithms, which provide important technical support for the real-time monitoring and control of the laser splicing process. The authors propose two multi-stage optimization algorithms to optimize the control efficiency and accuracy of the splicing actuator through the rotation optimization and translation compensation algorithms as well as the multi-stage heuristic optimization algorithms, which provide new ideas and methods for the precision and efficiency of the laser splicing process.

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