Research on Process Optimization of 3D Laser Cutting Robot for Three Dimensional Aluminum Components

Haibing Xiao*, Yongquan Zhou
Intelligent Manufacturing & Equipment School, Shenzhen Institute of Information Technology,
Shenzhen, Guangdong, China
*Corresponding Author.

Abstract

In order to solve the precision problem of laser cutting of 3D aluminum components, the influence of main process parameters on the characteristics of laser cutting was studied. Firstly, the model of 3D laser cutting of complex curved surface was studied, and the heat transfer mechanism of 3D laser cutting of aluminum materials was revealed. Through the three-dimensional laser cutting robot test bed, aluminum material is taken as the test object, the reasonable laser cutting parameters are selected, and the influence law of each process parameter on the cutting quality and the morphology of the slit is studied. Experimental studies shows that low surface roughness was achieved with some combinations of process parameters and attempts were made to optimize parameters in terms of cutting speed and laser power. It is obtained low surface roughness, with power 800w, cutting speed 40mm/s for 1mm aluminum.

Keywords: 3D laser cutting, cutting Process optimization, three-dimensional component, aluminum

I. Introduction

The application technology of 3D fiber laser cutting machine has been widely used in automobile manufacturing, engineering machinery, aerospace and other industries. Three-dimensional fiber laser cutting machine is an advanced laser cutting equipment, which is composed of special fiber laser cutting head, high-precision capacitive tracking system, fiber laser and industrial robot system for multi-angle, multi-directional flexible cutting of metal plate of different thickness. 3D laser cutting is the most widely used is the car body design and manufacturing, mainly used to develop new models, in car production line, deformation, such as cutting prototype parts, automobile body covering parts of cut hole, trimming, cutting the steering wheel hole, body wind deflector, the roof support, airbag parts, hydraulic molding parts, etc. The accuracy and stability of 3D robot laser cutting need to be improved. Kaebernick et al. [1] established a three-dimensional model of pulsed laser cutting. Nd-YAG laser was used to conduct oxygen-assisted cutting experiments on stainless steel, and the relationship between pulses and the width of slits was found to verify the reliability of the model. Three-dimensional robotic lasers with 5-axis CNC laser machine have been used for laser cutting [2,3]. Generation of 5-Axis Laser Cutting Path Based on STL Model was studied [4]. Three-dimensional consideration of jet impingement onto the kerf in relation to laser cutting process is modeled [5]. Zhu H [6] introduced an integrated process of CNC incremental forming and 5-axis laser cutting based on machining features, and the structure of related special CAD/CAM system as well as its development methods. Omer Ozgur Kardas et al. [7] simulated laser cutting aluminum alloy (2024 model) to study the stress and strain concentration phenomenon after laser cutting. Process Optimization of 3D Optical Fiber Laser Cutting Robot for Press Hardening of UHSS was put forward which is efficiency and quality are improved and a creative new offline programming method [8]. Hebing Xu [9] presents a methodology and algorithm of optimizing and smoothing the laser head orientation control for 3D laser cutting. The paper [10] presented a systematic methodology for on-site identification and energy-optimal path planning of an industrial robot. The identification experiments are carried out on-site, in a quick, non-invasive way. The article [11] deals with a method of thermal

cutting of materials, specifically with laser technology. Suitable technological parameters were determined on the basis of metallographic analysis, and the lowest heat influence on the material was achieved. Huang Y et al. [12] have used CO_2 laser cutting, and then the surface roughness of the sections cut using different laser parameters and ambient temperature was studied by a non-contact 3D surface profiler. Muys P et al. [13] stated that this simple model confirms in a capturing way the conjecture originally launched in that cutting speed can be increased with a factor of about 1.5 to 2 by switching over from circular to radial polarization. Kardas O O. et al. [14] put forward a method for Laser cutting of rectangular geometry in 2024 aluminum alloy. Cutting aluminum with fiber laser increases the cutting speed and gives a cut quality comparable with results obtained with CO and Nd: YAG lasers in continuous-wave (CW) mode that represent the most established laser sources for this application [15,16].Quintero F et al. [17] stated that The characteristics of the heat affected zone (HAZ) were studied related to the efficiency of the assist gas to eject the molten material. It has been demonstrated that the HAZ can be avoided with a suitable design of the gas injection system combined with an appropriate selection of the values of the processing parameters.

II. Theoretical Model of 3D Laser Cutting Robot

3D cutting robot system is to use the focus of high power laser beam of high energy density to the processing of 3D sheet, by controlling manipulator and laser processing technology, make be illuminate rapidly melting, evaporation and ablation of materials, at the same time with the aid of high-speed airflow and beam coaxial blow molten material, so as to realize sheet will be cut. The principle of 3D laser cutting robot is shown in Fig. 1.
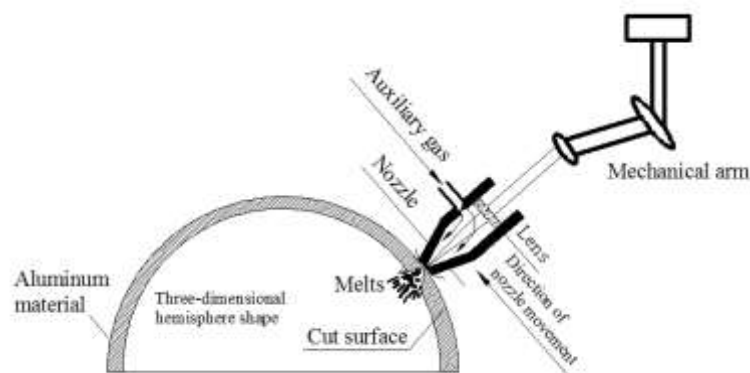

Fig 1: The principle of 3D laser cutting robot

Fig. 1 updated from previous works [18] that a model of 3D laser cutting machine is presented to obtain optional values of 5-axis motion coordinates at each cutter point when geometric information of cutter points on the cutting path is transformed to the motion coordinates of 5-axis. According to the motion analysis of the 3D laser cutting machine, the homogeneous coordinate information in the cutting head information controls the rotation angle of the laser beam normal vector:

$$\begin{bmatrix} x \\ y \\ z \end{bmatrix} = \begin{bmatrix} x - L_2 \sin\theta_B \cos\theta_C - L_1 \sin\theta_C \\ y - L_2 \sin\theta_B \sin\theta_C - L_1 \sin\theta_C \\ z - L_2 \cos\theta_B \end{bmatrix} \tag{1}$$

Where, x, y, z are three translation movements, θ_B, θ_C are the rotation angles of rotating B axis and C axis on the cutting head, and L_1, L_2 are the offset of the focal point of laser cutting head and the intersection point of B axis and C axis.

The process of absorbing laser light and then transferring heat energy to the interior of materials also abides by the basic laws of thermodynamics. The law of conservation of energy is as follows:

$$\frac{E_\alpha}{E} + \frac{E_\lambda}{E} + \frac{E_\mu}{E} = \alpha + \lambda + \mu = 1 \tag{2}$$

E means total energy, E_α means energy absorbed by material, E_λ means energy reflected by material surface and E_μ means energy lost by material transmission. α is the absorption coefficient of the material, λ is the reflection coefficient and μ is the transmission coefficient. The power density of laser beam is unevenly distributed in the spot irradiated on the surface of material, the absorption rate of material to laser during laser cutting and some thermodynamic parameters change with the increase of temperature, etc. The differential equation of heat diffusion is as follows.

$$\nabla^2 T(x,y,z,t) + A(x,y,z,t)k = \left(\frac{1}{\alpha}\right)\partial T(x,y,z,t)dt \tag{3}$$

$$\alpha = k/c_P \tag{4}$$

Where, T is temperature, which is a function of coordinates x, y, z and time t; α is the thermal conductivity coefficient, c_P is the volumetric heat capacity coefficient; k is the thermal conductivity; A is the heat released per unit volume per unit time, which is related to coordinates and time. By moving or rotating the mirror on each axis, the focal position and incident angle of the laser relative to the workpiece surface are changed for 3D laser cutting.

III. Experimental Equipment and Process

3.1 3D Fiber laser cutting robot system

The system composition of 3D laser cutting robot is shown in Fig. 2. The system consists of 2000W fiber laser, optical transmission system, laser cutting head, numerical control system, stabilized power supply, numerical control programming computer, water-cooled radiator, mechanical arm for controlling the movement of laser head, movable working platform, nitrogen gas tank for providing air pressure, dust removal system, etc.
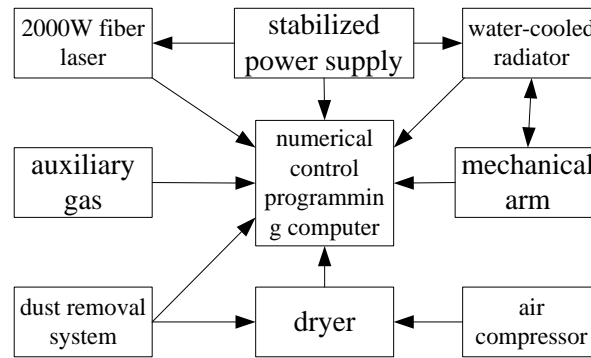
Fig 2: The system composition of 3D laser cutting robot

All parts of the 3D laser cutting machine system are closely related and complement each other: the stabilized power supply provides high-quality power supply for chillers, lasers and hosts; the water chiller provides cooling for the laser and the host, and other parts serve the host of 3D laser cutting robot machine. Photograph of 3D laser cutting equipment is shown in Fig. 3.
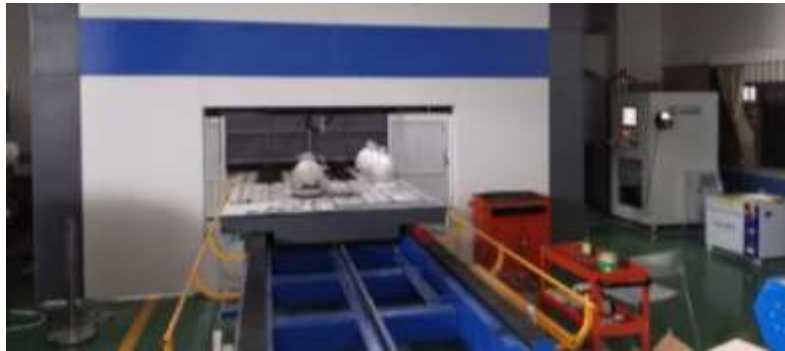

Fig 3: Photograph of 3D laser cutting equipment

3.2 3D modeling for laser cutting

Programming system is the interface between the whole laser cutting system and the operator. 3D modeling for laser cutting is builded through 3D modeling software (Fig. 4). At the same time, the corresponding axial data are transmitted to the computer, and the computer records them in the memory. The machining track between adjacent teaching points is automatically calculated by the system according to the given interpolation method, and finally the laser cutting of 3D curved surface is realized.

Fig 4: 3D modeling of aluminum components

3.3 Simulation and post-processing program

By designing 3D curved surface parts and selecting the option of "Surface Boundary", the starting point of serial connection can be dynamically selected, and the working coordinate system is increased. In the entity manager, the surface can be converted into an open sheet or a closed entity. Tool path simulation based on MasterCAM, which has many functions such as three-dimensional solid modeling, curved surface design, tool path simulation and realistic simulation. Is shown in Fig. 5 (a). MasterCAM provides an ideal environment for designing the shape of parts, and its powerful and stable modeling function can design complex curves and curved parts.In terms of machining, in the recalculation of other parameters do not need to be changed except for changing the tool diameter and tool angle radius, tool interference simulation is shown in Fig. 5 (b).
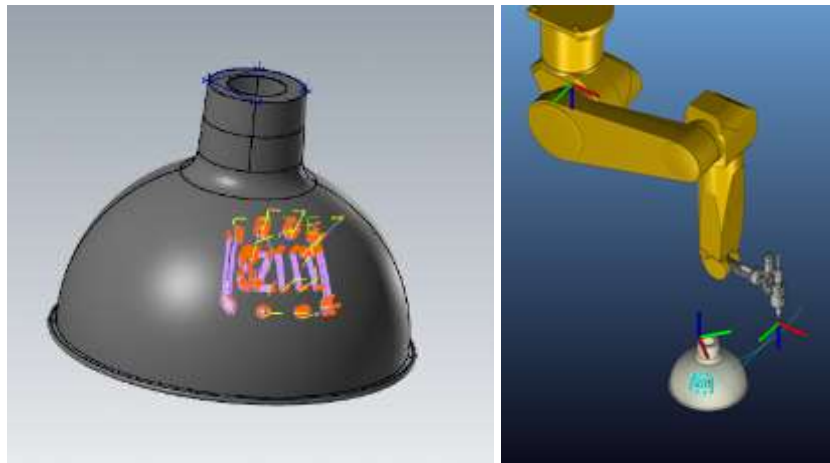
(a) Tool path simulation *(b) Tool interference simulation*
Fig 5: Tool path simulation based on MasterCAM

IV. Experimental Analysis

4.1 Laser 3D machining process and process parameters

Under the action of the light guiding system, the laser is guided from the output of the laser to the surface of the workpiece, and the required spot shape, power density and incident direction are obtained at the machining part. The spot moves relative to the surface of the workpiece according to a certain trajectory, and the interaction between the laser and the material completes the surface treatment of the workpiece in this process. The laser 3D cutting system with 5-axis changes the spatial position of focus by moving the mirror of optical path in X, Y and Z directions, and changes the laser exit direction by rotating the mirror on B and C axis, thus realizing 3D fiber laser cutting. The cutting process of 3D laser cutting robot shows the laser in Fig. 6.

Fig 6: 3D laser cutting process

Laser cutting parameters include laser power, cutting speed, focus position, pulse frequency, perforation delay and auxiliary gas etc. The relative position of the focus and the material to be cut (i.e., the focus position) and the working gas pressure are process parameters directly related to the laser cutting quality. The choice of gas type and the setting of working pressure depend on the type and thickness of the material to be cut. For the high pressure of nitrogen as gas, the gas pressure is usually 20bar, and the laser cutting process of aluminum alloy is shown in Table 1.

Table 1 laser cutting process of aluminum alloy

The process parameters	Numerical value	The process parameters	Numerical value
Thickness of aluminium	1 mm	Cutting power	500～2000W
Follow-up height	2mm	Cutting speed	25～50mm/s
Type of gas	N_2	Pulse frequency	5000hz
Type of gas	20bar	Perforated delay	10ms

In order to improve the cutting quality and ensure the machining accuracy for cutting aluminium, the perforation position can't be set directly on the cutting path, but on the plate waste near the starting point of the cutting path. The shape of space curved surface is complex. When trimming, the perforation position should be set on the horizontal plane or near horizontal plane as far as possible, and avoid setting at the inclined plane or corner. Auxiliary gas is mainly used to blow off slag from the cutting area, and can also cool the cutting material, reduce the heat affected layer and ensure that the focusing lens is not polluted. If the gas pressure is too small, the slag in the cutting area will not be removed by the gas flow, and it will not cut through or a large amount of slag will hang.

4.2 Collision processing and cutting path optimization

Previous works [19-21] respectively determined that, cutting aluminum with fiber laser increases the cutting speed and gives a cut quality comparable with results obtained with lasers that represent the most established laser sources for this application. With 3D laser cutting, the cutting head needs to track the normal direction of each point on the cutting track, and it needs to constantly change the motion posture. In some special positions during the movement, if the normal directions of the cutting head and the point on the cutting track are consistent, the cutting head will collide with the workpiece. In the process of physical cutting, if collision occurs, the cutting head, focusing lens and other equipment will be damaged, resulting in the loss of property. Therefore, when programming the cutting path, it is necessary to detect whether the cutting head and workpiece will interfere. Collision is effectively avoided, and cutting head and workpiece are protected.

4.3 Analysis of Experimental Results

The selection of laser power has an impact on cutting quality foe laser cutting. The cutting power should be determined according to the material and thickness of the cut pipe. If the power is too large or too small, a good cutting section cannot be obtained. When laser cutting, the laser power is too small, which makes it impossible to cut, while the light one produces cutting melt stains and produces tumor scars on the cutting section. If the laser power is set too high, the whole cutting surface will melt or the opposite side of the pipe will melt, and the cutting seam will be too large, resulting poor cutting quality. With proper setting of laser power and cutting gas and pressure, good cutting quality can be obtained without melting stains. The cutting speed is determined according to the cutting material and thickness. Different cutting speeds will have a great impact on the quality of laser cutting.

The influence of cutting speed on the quality of cutting seam, the faster cutting speed, the smaller heat diffusion,

the narrower heat affected zone and the better laser cutting quality; when the cutting speed is too fast to form a stable slit, the cutting speed must be reduced. Fig. 7 shows the variation of the width of the slit with cutting speed. The slit will spread along the direction of relative movement between the laser beam and the workpiece, and the more energy obtained, the wider the slit will be; Choosing proper cutting speed can not only improve the efficiency of laser cutting, but also get good cutting quality.

It can be seen from Fig. 8 that the roughness value of the cutting section decreases first and then increases with the increase of cutting speed. With the increase of cutting speed, the surface becomes smooth, and the quantitative index is that the roughness value decreases. However, when the cutting speed increases, too much energy is incident on the surface of the cut aluminum material, which will lead to poor quality of the aluminum surface.
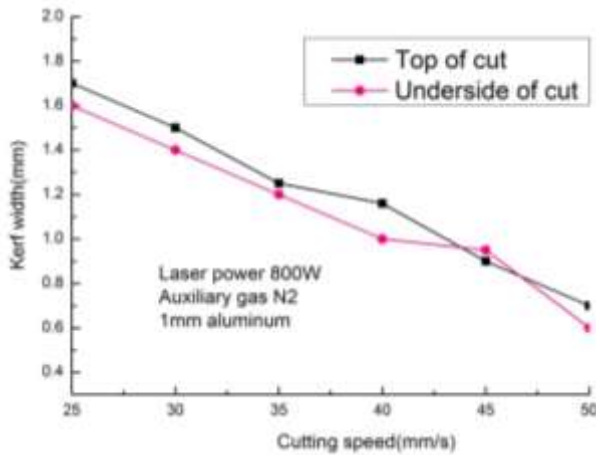

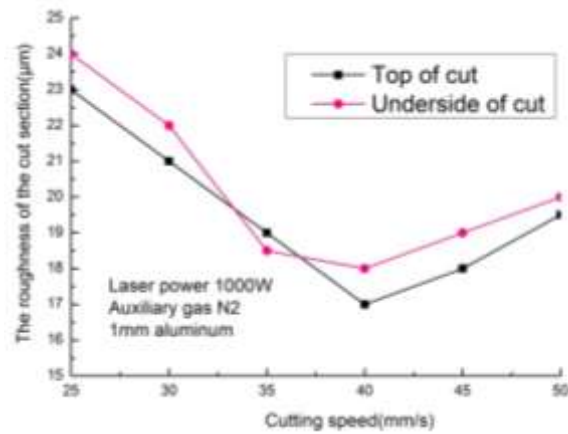Fig 7: The variation of the width of the slit speed

Fig 8: The variation of the roughness with with cutting with cutting speed

Fig. 9 is three-dimensional sample after laser cutting. The cutting section of aluminum is analyzed and observed by using scanning electron microscope. According to the analysis results, the laser cutting quality and cut samples are scanned by electron microscope as shown in Fig. 8.
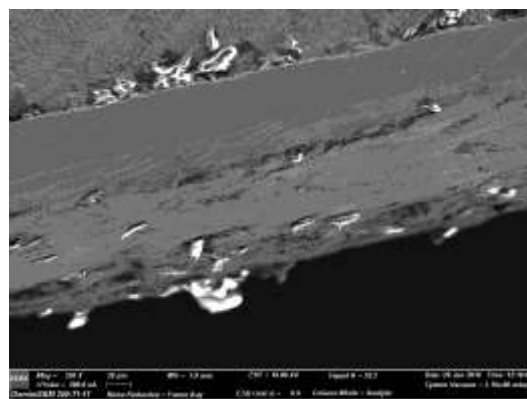

Fig 9: Three-dimensional sample

Fig 10 : SEM of the cut section

V. Conclusion

Laser power and cutting speed are the main process parameters 3D for laser cutting. To reduce the surface roughness of the cut section, a new process optimization of 3D laser cutting robot for three dimensional aluminum components is proposed. The results indicate that under the condition of a certain laser power, the selection of

cutting speed is determined according to the material and thickness of the cut. Different cutting speeds will have a great impact on the quality of laser cutting. The selection of appropriate cutting speed can improve the efficiency of laser cutting and reduce the surface roughness.

Acknowledgements

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