

Research on NC laser combined cutting optimization model of sheet metal parts

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Abstract. The optimization problem for NC laser combined cutting of sheet metal parts was taken as the research object in this paper. The problem included two contents: combined packing optimization and combined cutting path optimization. In the problem of combined packing optimization, the method of “genetic algorithm + gravity center NFP + geometric transformation” was used to optimize the packing of sheet metal parts. In the problem of combined cutting path optimization, the mathematical model of cutting path optimization was established based on the parts cutting constraint rules of internal contour priority and cross cutting. The model played an important role in the optimization calculation of NC laser combined cutting.

1. Introduction

NC laser combined processing technology combining computer numerical control technology and laser cutting technology, has the advantages of reliable quality and high cutting precision etc., and has now become the important processing method in the process of plate cutting. The laser cutting path generated by CAM (Computer Aided Manufacturing) NC program, has a great influence on cutting process and machining efficiency. Optimizing the cutting path can significantly shorten the cutting time and improve the quality of processing.

Han etc.[1] used the simulated annealing algorithm to solve the cutting path optimization problem of irregular sheet metal parts; Pan, etc. [2] set up a “punching and cutting” integrated planning CAD/CAM system based on the technology of knowledge base; The three-step algorithm based on hierarchical planning idea, proposed by Hui-xia Liu [3], used to optimize the cutting path problem; according to graph theory, Sa Chen [4] proposed an effective algorithm to optimize cutting path based on Prim algorithm; Jian-tao Li [5] carried on the global and local optimization of two-dimensional rectangular parts cutting path.

The problem of cutting path optimization was researched at many different angles in the above documents, but most of them researched cutting metal parts inside a rectangular plate, which is not fit for assembled cutting conditions based on several plates. On the other hand, it is inevitable that there will be remnants during long-term production process in large sheet metal parts manufacturing enterprises, in order to save material and reduce cost, the excess material is preferentially used. Currently, the related research of excess stock layout and cutting optimization method is relatively small.



Taking the combined cutting optimization problem inside several plates as the research object, the NC laser combined packing and cutting path optimization inside irregular remnants was mainly discussed in the paper to solve some key problems in excess material recycling.

2. Description of combined cutting problem of excess material

Assumed to be the location of the cutting parts inside excess material has been determined by relevant layout algorithm. Due to remnants are relatively small and irregular, in the process of cutting, machine need to restart and plate need to load and unload constantly, which is tedious and time consuming, and seriously affects the processing efficiency. Therefore, currently, the combined cutting method of excess material is adopted, that is, let several plates place in the cutting area of the cutting machine, then one-time cutting is finished by laser head and the next batch of excess material is loaded. As shown in fig.1, the remnant S1 has three parts with hole P_{11} , P_{12} and P_{13} to be cut, similarly, S2, S3 and S4 have P_{21} , P_{31} , P_{41} and P_{42} respectively, let S1, S2, S3 and S4 in the rectangular cutting area of the cutting machine without overlapping, then 7 parts (P_{11} , P_{12} , P_{13} , P_{21} , P_{31} , P_{41} and P_{42}) were cut by laser head at a time, the processing method is called excess material combined cutting. The method can effectively save the processing time and improve processing efficiency.

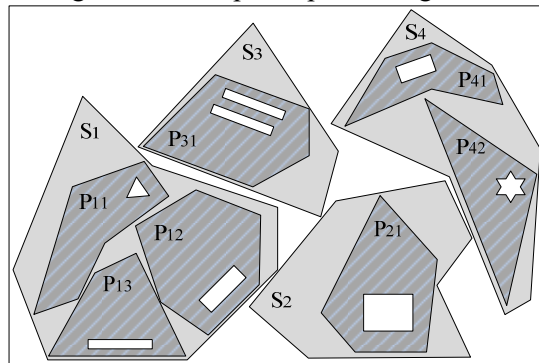


Figure 1. Example of combined cutting problem inside excess material

The combined cutting problem of excess material includes two contents: 1) Combined packing optimization. Through packing optimization, more remnants can be packed with the best location in the cutting area to improve the single cutting production; 2) Combined cutting path optimization. Through laser cutting path optimization during processing, the idle travel of laser head can be effectively reduced so as to shorten the cutting time and improve efficiency.

3. Combined packing optimization of excess material

3.1. The method of combined packing optimization of excess material

Combined packing optimization of excess material is a typical two-dimensional irregular part packing optimization. So the developed method can be used for the solution, such as the packing method of rectangular fitting, NFP (No Fit Polygon, critical polygons) algorithm, intelligent search packing algorithm, etc. The geometry contour of remnants is equivalent to the external contour of unpacked part in conventional two-dimensional irregular packing, but the internal and external contour of unpacked parts inside excess material is equivalent to the internal contour of unpacked part in conventional two-dimensional irregular packing. In order to improve the computation efficiency, first the geometry contour of remnants is calculated, and then the geometry coordinate of graphics inside excess material is updated by the method of geometric transformation. The method reduces the packing calculation effectively, and greatly increases packing speed. Based on the current literature, “genetic algorithm and gravity center NFP” are adopted to solve packing problem in the paper. Algorithm steps are as follows:

Step1. Initialization. First sort all plates by non-increasing ordering of area and obtain initial

ordering, then generate the first generation by variation; let the current evolutionary generation $gn = 0$; Initialize the biggest evolutionary generation GN.

Step2. Population evolution.(1) choice: randomly select two individuals in the population as the parent individual Parent1, Parent2;(2) cross: if the crossover probability is not less than Random $[0,1]$, new child Child1 and Child2 are produced through parent individual genetic crossover, otherwise the genes is passed on directly;(3) variation: if the mutation probability is not less than Random $[0,1]$, the gene of the individual Child1, Child2 gets mutation;(4) calculate the fitness of Child1 and Child2;(5) generate a new population: join the individual Child1, Child2 to the new group, if the number of individuals in the new group is less than the number of individuals in original group, go to step (1); Otherwise, go to step 3.

Step3. Calculate the fitness of individual. Update the current best individual and the global optimal individual.

Step4. Determine whether terminate evolution. If $gn \geq GN$, the population evolution terminates, turn to Step5; Otherwise, go to Step2.

Step5. According to the gene coding of the global optimal individual, the packing sequence of plates is acquired.

Step6. According to the packing sequence of plates and the location selection rules based on gravity center NFP, packing optimization is done for all the remnants to obtain the packing result.

3.2. The geometric transformation of graphics inside excess material

After combined packing of excess material, the geometry coordinates of the new plates outline are acquired, and the geometry coordinates of graphics inside excess material need to be updated. It is known that the shape and size of plates remains the same, just their locations change by analysis. Thus, the process of packing is essentially the geometric transformation process of graphics. The graphics before and after packing can be called old graphics and new graphics respectively, according to the geometric transformation theory of two-dimensional graphics, the process of graphics transform should satisfy the following formula:

$$A \times T = B \quad (1)$$

In the formula, A denotes the point set matrix of old graphics, T represents transformation matrix, and B denotes the point set matrix of new graphics. For the convenience of calculation, select three vertices from all vertices of remnant S_i as reference points, the original coordinate matrix before packing is:

$$A_i = \begin{bmatrix} x_1 & y_1 & 1 \\ x_2 & y_2 & 1 \\ x_3 & y_3 & 1 \end{bmatrix} \quad (2)$$

The new coordinate matrix after packing is:

$$B_i = \begin{bmatrix} x'_1 & y'_1 & 1 \\ x'_2 & y'_2 & 1 \\ x'_3 & y'_3 & 1 \end{bmatrix} \quad (3)$$

For there are only translation and rotation in the process of packing, the transformation matrix is:

$$T_i = \begin{bmatrix} a & b & 0 \\ c & d & 0 \\ l & m & 1 \end{bmatrix} \quad (4)$$

According to the formula (1), the formula (5) was obtained:

$$\begin{bmatrix} x_1 & y_1 & 1 \\ x_2 & y_2 & 1 \\ x_3 & y_3 & 1 \end{bmatrix} \times \begin{bmatrix} a & b & 0 \\ c & d & 0 \\ l & m & 1 \end{bmatrix} = \begin{bmatrix} x'_1 & y'_1 & 1 \\ x'_2 & y'_2 & 1 \\ x'_3 & y'_3 & 1 \end{bmatrix} \quad (5)$$

The formula (5) is a standard linear equation with 6 unknown numbers, the unknown numbers a, b, c, d, l and m are solved easily (the solving process is abbreviated). Thus, the transformation matrix T_i can be obtained. In the process of packing, the relative location of graphics inside remnant S_i keeps invariant, so the geometry coordinates are also change according to the transformation matrix T_i . In the correlation model of graphics data, denote the original coordinate's matrix of outside contour vertices of parts inside remnant S_i as A_{io} , the new coordinate's matrix after packing is denoted as B_{io} ; accordingly, denote the matrix of inside contour vertices as A_{ii} , the new coordinate's matrix after packing is denoted as B_{ii} . According to the formula (1), there are:

$$B_{io} = A_{io} \times T_i \quad (6)$$

$$B_{ii} = A_{ii} \times T_i \quad (7)$$

The transformation matrix of each plate can be calculated according to the formula (5), and then according to the formula (6) and (7), the geometric transformation of graphics inside all remnants is carried on, finally, the relevant geometry coordinates in the correlation model of graphics data are updated according to the calculation results.

4. Combined cutting path optimization inside excess material

4.1. Parts cutting constraint rules

According to the requirements of cutting process, in cutting process, the following two constraint rules should meet:

(1) The principle of from internal to external

In order to reduce the deformation of parts in the process of cutting, usually adopt "first cutting internal contour cutting, then external contour" method, the principle has been approved in general. The three layer correlation model of graphic data is introduced to describe the geometry information of graphics in section 3.1, in the model, the geometry data layers of internal and external contours of parts are clear and interconnected, while cutting path optimization calculation, the data of part's internal and external contours could be quickly identified.

(2) The principle of cross cutting

At present, under the influence of "equivalent TSP method", the serial cutting principle of parts is adopted in most of the literature, that is, another part can be cut only after the previous part is cut by the laser head. The serial cutting principle has certain influence on the cutting path optimization result, sometimes, it may lead optimization algorithm not to find the global optimal solution. For solving the problem, the cross cutting principle of parts is put forward, that is, in the process of cutting, let the laser head removes among different parts and does cross cutting. The principle leads optimization algorithm to find a better optimal solution.

4.2. The optimization mathematical model of cutting path

In the process of machining, when the laser head cuts parts, it is in working state; when it removes among the contours of different parts, it is idle, known as idle travel. The goal of cutting path optimization is to make the distance of idle travel the shortest in order to improve machining efficiency. For adopting the cross cutting principle, all internal and external contours of parts to be cut must be discretized into line segment groups, so the cutting path optimization problem is equivalent into cutting sequence planning problem of each contour line segment. By the two examples shown in table 1, it is known that the distance of transferring from endpoints of various line segments is bigger

than that of transferring with the shortest distance between various line segments, so in order to shorten the idle travel, the principle of "transferring with the shortest distance between various line segments" should be followed. The shortest distance formula between line segment and is:

$$d_{\min} = \min(d_1, d_2, d_3, d_4) \quad (8)$$

In the formula, d_1 denotes the shortest distance from point A to line segment CD , d_2 represents the shortest distance from point B to line segment CD , d_3 signifies the shortest distance from point C to line segment AB , and d_4 denotes the shortest distance from point D to line segment AB .

Table 1. Example of laser head transfer path

Name	Transfer from endpoints	Transfer with the shortest distance	Transfer path
Example 1			$AB > AP$
Example 2			$AC > PC$

Assuming that the cutting sequence of contour lines is shown in table 2. Z denotes the number of all contour lines, the laser head start from origin point $O(0, 0)$. The cutting path of laser head is: $O \rightarrow [LP_{11} \rightarrow LP_{12}] \rightarrow [LP_{21} \rightarrow LP_{22}] \rightarrow \dots \rightarrow [LP_{Z1} \rightarrow LP_{Z2}] \rightarrow O$. Idle travel

$$S_e = \overline{OLP_{11}} + \overline{LP_{12}LP_{21}} + \overline{LP_{22}LP_{31}} + \dots + \overline{LP_{Z-1,2}LP_{Z1}} + \overline{LP_{Z2}O} \quad (9)$$

Therefore, the mathematical model of cutting path optimization problem is as follows:

$$\min S_e = \sqrt{x_{11}^2 + y_{11}^2} + \sum_{i=1}^{Z-1} \sqrt{(x_{i+1,1} - x_{i,2})^2 + (y_{i+1,1} - y_{i,2})^2} + \sqrt{x_{Z2}^2 + y_{Z2}^2} \quad (10)$$

$$\text{s.t. } x_{ij} \geq 0 \quad (i = 1, 2, \dots, Z; j = 1, 2)$$

$$y_{ij} \geq 0 \quad (i = 1, 2, \dots, Z; j = 1, 2)$$

Table 2. Cutting sequence of parts contour line

No.	Line segment	Endpoint 1 and its coordinate	Endpoint 2 and its coordinate
1	L_1	$LP_{11}(x_{11}, y_{11})$	$LP_{12}(x_{12}, y_{12})$
2	L_2	$LP_{21}(x_{21}, y_{21})$	$LP_{22}(x_{22}, y_{22})$
3	L_3	$LP_{31}(x_{31}, y_{31})$	$LP_{32}(x_{32}, y_{32})$
4	L_4	$LP_{41}(x_{41}, y_{41})$	$LP_{42}(x_{42}, y_{42})$
.....
Z	L_Z	$LP_{Z1}(x_{Z1}, y_{Z1})$	$LP_{Z2}(x_{Z2}, y_{Z2})$

5. Conclusion

In the process of cutting parts inside irregular excess material, it is very necessary to solve the optimal combined packing scheme and the shortest cutting path; the optimization solution can effectively improve the cutting efficiency and shorten the processing time. The method proposed in the paper to solve NC laser combined cutting optimization problem inside irregular excess material is also has certain reference value to the similar problem. However, it is a new subject, which also has a lot of unsolved problems, and still need to be further in-depth studied.

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