Steel Plate Cutting Path Optimisation Problem Based on Euler's Theorem and Greedy Algorithm

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Abstract. Steel plate cutting as one of the key technologies in the field of machining, planning the optimal path and reducing the air distance can improve the cutting efficiency of the steel plate, and improving the cutting efficiency is the most critical step in the machining process. In this paper, we analyze the main reasons for the generation of empty paths and make the assumption of cutting the whole part at once while cutting the part. On this basis, Euler's theorem and greedy algorithm are used to find the proximal point of the cutting path from the outer contour to the inner contour, and to plan the optimal path and the resulting shortest air distance for a given cutting of the outer contour of the serrated steel plate as well as the cutting of different shapes of parts in the inner part of the serrated steel plate. The resulting shortest air travel distance is 31.5536 by matlab.

Keywords: Euler's Theorem, Greedy Algorithms, Steel Plate Cutting, Path Optimisation.

1. Introduction

In the process of ship production, steel plate cutting is the most important process in the production chain, and a reasonable cutting path can not only save the cutting time and shorten the construction cycle, but also greatly save the cost of ship production.Steel plate cutting refers to the project of cutting and processing according to the shape and size required by the part design drawings. Cutting and discharging as a more important process in the steel structure manufacturing industry, the efficiency, quality and dimensional accuracy directly affect the production progress of the next process and the quality and progress of the whole project [1]. Excessively ineffective cutting time will inevitably lead to an increase in the total cutting time so that the cutting task cannot be completed on time. To solve this engineering problem, it is necessary to plan the optimal cutting path [2]. In recent years, based on the development of CAM nesting software, the realisation of the traditional manual nesting to human-computer interaction semi-automatic nesting, and then automatic nesting based on a variety of super algorithms. However, some companies in the steel cutting, but still stuck in the "can cut" stage, as long as the cutting programme can be generated to complete the cutting can be, often ignoring how to "cut well" (cutting continuously and smoothly), "cut fast" (cutting efficiently),"cutting economically" (high utilisation of plate, saving material), resulting in a waste of materials and time [3]. In the process of steel plate cutting and processing, the key to improving processing efficiency, completing the machining task with a shorter path and saving more material is the optimisation of the cutting path.To address this problem, mainstream enterprises in the industry have been seeking more efficient steel plate cutting process, and in practice, continuous innovation and improvement [4]. In this paper, the greedy algorithm and Euler's theorem are used to find the optimal path of steel plate cutting, and use the matlab program to find the proximal endpoint distanceand and finally the shortest cutting air distance is calculated.

2. Fundamentals of the greedy algorithm and Euler's theorem

For the problem of planning the cutting path of a steel plate, the first step is to define the cutting task. Cutting the entire outer contour of the part with the designed inner small parts. In this process, it starts from the starting cutting point and then reaches the starting point of another internal part,

which is cut and then cuts another part after the internal part is cut. If the internal part is considered as a mass point, this is similar to the famous "Seven Bridges Problem":Starting from a fixed starting point, passing through each location only once, and finally returning to the starting point.In addition, considering the characteristics of this research problem, after completing a local cutting job, generally do not choose a distant part as the next cutting object, so this research problem also exists local greedy [5]. The greedy algorithm is a simple and efficient method for solving the near-optimal problem, which can well solve the problem of improving cutting efficiency and saving cutting time [6].

Greedy algorithm, is a typical algorithm used to solve optimal solution problems. It is the local optimal solution obtained by optimizing the local solution without considering it from the overall optimum.[7]. In the process of solving a problem, it will make choices that are optimal for the current view. The most important feature of the greedy algorithm is that it proceeds step by step, which makes it more efficient and the algorithm simpler and faster when solving a certain problem.

The basic steps of the greedy algorithm are shown below [8]:

(1) Establishing appropriate mathematical models for describing relevant problems;

(2) Decomposing the problem to be solved into several smaller subproblems;

(3) Solving each subproblem to obtain the subproblem optimal solution, In other words,the local optimal solution[9];

(4) Integrating the local optimal solutions of the obtained subproblems into the solution of the original one.

A relevant problem that can be solved by a greedy algorithm must have the following two characteristics:

The first is the greedy choice property.The optimal solution of a problem can be achieved by integrating the local optimal solutions.The second is the optimal substructure property. This is the core property of the greedy algorithm.The relationship between the local optimal solution and the overall optimal solution.

Overall, the greedy algorithm, although there will be a little limitation in solving the problem, it saves a lot of time spent on exhausting all the possible solutions in order to find the optimal solution, and greatly improves the efficiency of solving the problem. Therefore, the greedy algorithm is an appropriate choice for solving the problem.

The problem is very similar to the "Seven Bridges Problem". It originated from a game in which a river called the Pregel(Kaliningrad in the former Soviet Union, now the capital of Kaliningrad Oblast in Russia). Here a river named Pregel and its tributaries divide the banks of the river and two river-centered islands into four parts, which are connected by seven bridges, as shown in Figure 1.In the 18th century, a local game was popular in here: Could a person start from a certain place (riverbank or island), cross each bridge once and only once, and finally return to the starting point? This game is the famous Seven Bridges Problem [10].



Figure 1. The Seven Bridges of Gönigsberg

The mathematician L. Euler (1707-1783, Swiss mathematician), who was then working at the Petersburg Academy of Sciences.He gave an answer about this problem in 1736, firstly by abstracting it into a mathematical model: The four points (also called nodes) are used to represent land and islands, and the connecting lines (called connecting edges or paths) between the four points are used to

represent the seven bridges, as shown in Figure 2.This treatment is also known as the graphical symbolic representation of the actual problem, and after this treatment, the seven bridges problem is transformed into a "one stroke" problem. Euler's answer consists of only four sentences:

1. Each path has only one starting point and only one ending point;

2.All nodes have an even number of connected edges except the start and end points;

3.If seven-bridge problem have a solution, all nodes must have an even number of connected edges;

4.The mathematical model of the Seven Bridges problem is not such, so the Seven Bridges problem has no solution[10].

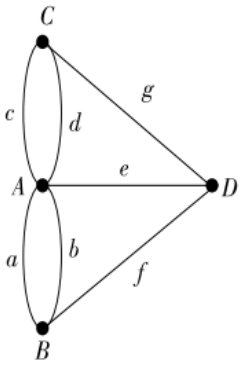


Figure 2. Mathematical model of the seven-bridge problem

The above seven-bridge problem brings great inspiration to what is studied in this paper, and by thinking about the research of this problem, it helps us to plan the optimal cutting path to get the shortest air distance.

3. Results

The algorithm flow is as follows:

(1) Initialization: the cut point (B1) is the starting point and is assumed to be a known shortest distance of length 0. And Creating a set for all remaining unvisited nodes and setting the shortest distance of all remaining nodes to infinity.

(2) Select the current node: Select the shortest distance of an unvisited node in the newly created set as the current node, and remove it from the node set after the selection is completed.

(3) Update neighbor nodes: select all the neighbor nodes of the current node, and assume that if the reach to that neighbor node is less than the previously calculated shortest, then this distance will be used as the shortest distance to the neighbor node.

(4) Repeat process 2 and 3, using the shortest distance where all nodes have been visited or the target node is known as the stopping criterion.

Applying Euler's theorem, it follows that the following two conditions must be satisfied in order for each figure to be drawn in one stroke:

(1) The graphs must be connected;

(2) The number of singularities in the graph must be 0 or 2.

Therefore, a right-angle coordinate system is established with point B4 as the centre of the circle, with the horizontal axis as X and the vertical axis as Y. The coordinates of point B1 (the starting cutting point) can be obtained as (80,0), and the known line segments are y=15 (20<x<60), y=35 (20<x<60), x=20 (15<y<35), x=60 (15<y<35). The coordinates of point B1 are known to be (80,0), and it is known that point 2 (any point other except B1) is on a closed path consisting of four line segments, the four segments being (y=15(20<x<60), y=35(20<x<60), x=20(15<y<35), x=60(15<y<35)), finding a point on the path making the distance between the two points the shortest. The null range problem that arises in this problem is also the distance that arises when using Euler's theorem.

In the steel cutting process, certain assumptions need to be made for better planning of the cutting path. Therefore, the following assumptions are made in this paper:

(1) Consider each bore part as a closed loop, and cut the part along the closed loop in one pass;

(2) The machine operates without air travel due to cornering;

(3) Assumptions about the form of the parameters in the model.

During the cutting process, it is first of all necessary to be clear about the main reason for the air travel: The outer contour is fully serrated and the entire contour needs to be cut.If only the outer contour is cut, there is no air travel in the process. In practice, however, we need to cut the inner contour, which results in air travel between the inner and outer contours. In addition, the complexity of the problem is that the inner contours to be cut are four circles and one ellipse. In the cutting process, if the cutting route is not well designed, it will lead to ellipse and circle may also produce empty travel during the switching process.Therefore, it is necessary to design a reasonable cutting path to diminish the air distance as much as possible. In summary, the main reasons for the cutting path to generate air distance are two aspects, one is the cutting of internal and external contours in the switching process to generate air distance,the other is the cutting of different internal contour parts in the switching process to generate air distance.

During the cutting process, a greedy strategy is used to select the next cut point, and the cuts follow a straight path between the two cut points.This strategy will move from the nearest cut shape to the next nearest cut shape, thus reducing the air travel. This algorithm perfectly avoids the potential for air distance that can be generated by switching between circular and elliptical cut paths. Therefore, the paths that generate air travel are mainly by switching between the outer contour and the circle, and by switching between the outer contour and the ellipse.

(1)First, the cutting follows the closed outer contour, and when the proximal point of the bore part is encountered (the proximal point is the point on the contour of the bore part that is closest to the outer contour and the corresponding point on the outer contour), the cutting of the bore part begins. In this process, the cutting process starts from the starting cutting point B1, passes through B1 → B2.Start cutting the first circle as it passes the B5 endpoint directly above the first circle, and then returns to the B5 endpoint again after the cutting is completed. At this time, two sections of the same distance of the air distance,the distance of this airspace is from the upper endpoint of the circle to the outer contour. After returning to the B5 endpoint, the cut is again made along the outer contour of the serrated plate, and when the proximal endpoint B6 of the ellipse and the serrated plate is reached, the cutting of the ellipse begins. After cutting a circle along the outer contour of the ellipse, the second circle is encountered by again cutting forward along the serrated plate. During this process, the resulting air distance is the closest distance from the endpoint B6 to the proximal endpoint of the ellipse. After returning to the B6 endpoint, continue cutting along the outer contour, cutting remains the same as in the previous cutting process, when looking for a write a hole parts near the end point, that is, start cutting the next hole parts until the complete cut is completed. And so on, until the completion of the entire steel cutting, and return to the B1 point. The cutting path is shown in Figure 3 shown.

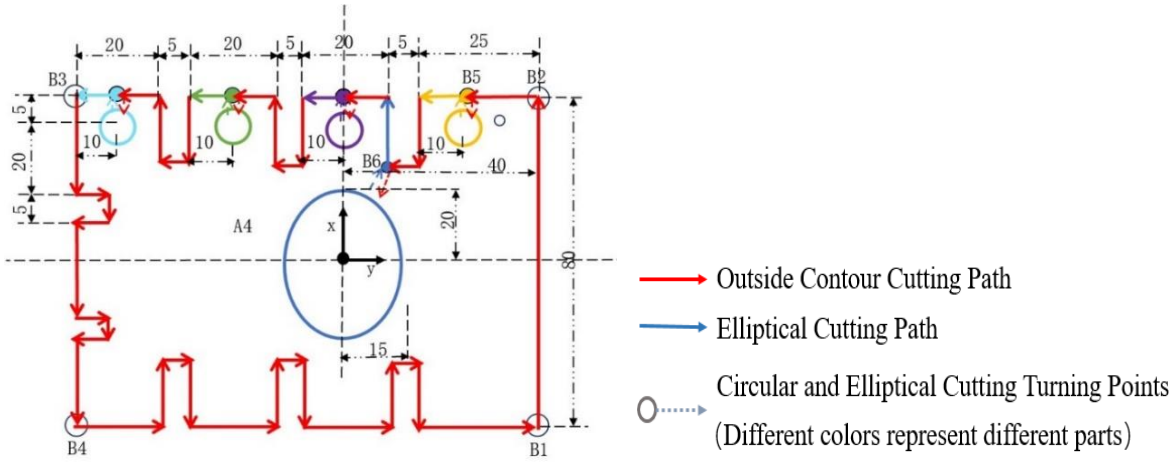


Figure 3. Schematic diagram of cutting path

In this process, we need to determine how far the point B6 is from the proximal endpoint of the ellipse. Therefore, we establish a Cartesian coordinate system with the centre of the ellipse. As shown in figure 3, the long axis of the ellipse is the X-axis and the short axis is the Y-axis, which gives us the coordinates of B6 as (25, 10). According to the matlab program operation, the closest distance of B6 point from the ellipse is 7.7768. The position of point B6 in relation to the ellipse is shown in Figure 4. From this figure, it can be verified that point B6 is indeed located outside the ellipse and has the closest distance to the ellipse.

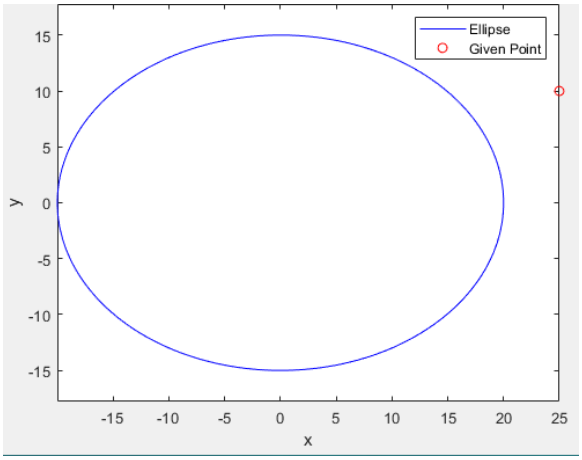


Figure 4. Plot of the ellipse in relation to the distance from point B6

4. Conclusion

In the above process, We can derive the optimal path for this sheet cutting. That's cutting along the outer contour first, and every time we encounter a proximal point, Switching to the part of the bore where the proximal point is located until the entire bore part is cut. Therefore, the entire cutting path is starting from the starting point B1, along the outer contour, when the first proximal point is encountered, start cutting the first bore part, after cutting this part, cut along the outer contour again until the second proximal point is encountered, start cutting the ellipse, after the ellipse has been cut, cut along the outer contour again,the cutting path is the same as that of the first circle.

In this process, the path that generates the air distance is when the outer contour is switched with a circle and when the outer contour is switched with an ellips,and each switching will generate the same two air distances. Therefore, the total air distance is 31.5536. This paper is an important guide for the optimal path planning of complex parts and the calculation of the shortest air distance, and it is of great significance for the real production.

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