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Formation of an Energy-Efficient Cutting Tool Path in Waterjet and Laser Cutting CNC Machines

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Abstract—The paper deals with generation of a cutting tool path taking into account the features of waterjet and laser machines. We present a problem model for the standard cutting technology, i.e., every contour contains only one incised point and the contour can be cut out along a single continuous line. The criterion is the duration of cutting tool idling, which has to be minimized. In this model problem, electric power is conserved due to reduction of idling time. It is pointed out that the problem is considered to be an *NP*-hard one. We describe both common and specific restrictions. The common restrictions do not depend on machine type. The specific restrictions for the waterjet and for the laser machines are different. Three primary stages of cutting tool path generation are distinguished. At the first stage, the sets of possible incised points for every contour are generated taking into account the features of the selected machine type. At the second stage, the initial permutation of contours and the only incised point for every contour are selected by a greedy algorithm. The third stage is optimization of the initial solution by two metaheuristics at the same time—Great Deluge Algorithm (GD) and Threshold Accepting (TA). The best solution of the two obtained is selected. The experiment is performed in the ITAS NESTING nesting system to show the efficiency of method. The obtained solution for both waterjet and laser machine satisfies all restrictions and features. The proposed method shows high performance. It takes the algorithm 3 s on average to find a solution for the waterjet machine and 2 s to find solution for the laser machine based on data on 152 contours.

Keywords: CNC machine, cutting tool, cutting technology, idling time, path optimization
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Modern integrated CAD/CAM systems can significantly increase the output of cutting CNC equipments. As a rule, when cutting sheet material using such systems, the sheet with the placed details is designed in the CAD module; then, the CAM module carries out the generation of the control program (CP), which consists of a sequence of G-codes. The created program controls the movement of the cutting tools (CTs). The overall cutting time, power consumption, cutting cost, and a number of other characteristics depend on the path. Some of them are dependent.

To date, many studies related to the formation of the path of a cutting tool have been carried out. These works have mainly been carried out in two areas: specification of problem formulation and development of new algorithms for seeking a solution, which is, as a rule, approximate.

Despite the large number of works devoted to this problem, only a few of them consider various features of the processing equipment in the algorithms for constructing the CT path. However, it is necessary to pay greater attention to these features with the development of integrated CAD/CAM systems, which are capable of working with equipment of different types and manufacturers.

The aim of this paper is to develop an algorithm for constructing the cutting tool path taking into account particular waterjet (WJC) and laser cutting machines.

The problem of minimizing length of idling L_{xx} using standard technology of cutting will be solved for the construction of the CT path, when the only incision point (input or output) is selected on each contour, and the contour is cut out in one continuous line without switching off of the tool. The total number of incision points coincides with the total number of contours (one contour is one incision point). This problem is that *NP*-hard ones [1] exclude the possibility of using exact methods, as the number of contours on a real cutting map is large. We will note that it is possible to reduce power consumption by only reducing the CT idling time.

Two methods were chosen to solve the problem:

—flood algorithm (Great Deluge Algorithm, GD); and

—method of threshold acceptability (Threshold Accepting, TA).

The transition to a new solution is carried out using the GD, if the criterion value is better than a specific amount (the water level) that is reduced in the minimi-

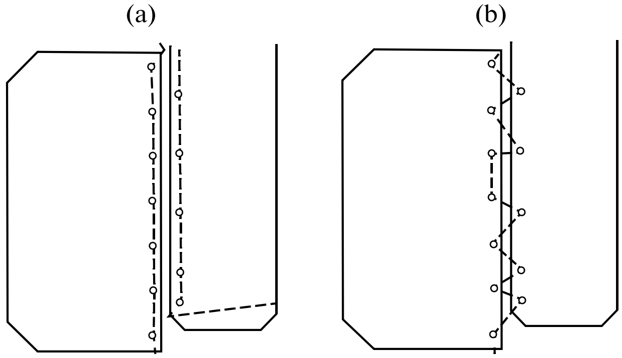

Fig. 1. Transition order between the details in the presence of internal contours for the machines using (a) waterjet and (a, b) laser cutting.

zation process. The TA method selects a new solution if it is not much worse than the current one. A detailed description of the metaheuristics can be found in [2].

The advantages of these metaheuristics are a simple algorithm structure and the small number of operations carried out in finding the solution. In addition, the GD and TA methods, unlike many other metaheuristics, depend on only one parameter, which simplifies using them for the solution of specific problems.

We will consider the problem of minimizing the idle time in the described statement. Let M be blanks and N be contours ($N_i \geq M$). All contours are classified as internal or external in relation to the blanks. Each contour is set by a set of arcs and segments or can be a circle, as the majority of cutting machines can operate only with these primitives [3]. Let also p_i be an incision point for each blank contour $i = 1, 2, ..., N$. Point p_0 is the initial position of the tool. It is necessary for determination of the order of contour cutting and coordinates of incision points that the total length of the tool movement between contours be as small as possible; i.e., it is required to minimize the function

$$L_{xx}(s) = \sum_{i=1}^{N} \sqrt{(x_i - x_{i+1})^2 + (y_i - y_{i+1})^2} + \sqrt{(x_N - x_0)^2 + (y_N - y_0)^2},$$

where s is the admissible circuit of contours, which consists of exchange of a sequence of incision points; and (x_i, y_i) are coordinates p_i of incision points.

The following restrictions are required for the circuit of contours to be admissible:

—the path needs to begin and end at p_0;

—the path needs to pass through only one point of the contour (the incision point);

—if the detail has internal contours, it is necessary that they be cut out to the external contour (precedence condition of contours);

—if the blank is enclosed in the free space of another part, it should be cut our first; and

—the incision point should be displaced concerning the contour at some size as the incision and the cut should be carried out at a distance from the blank contour; if the contour is external, the displacement is carried out outside, while, if it is internal, this happens inside.

We will consider some features of generating the cutting tool path in waterjet and laser machines that are considered in the construction of the algorithm.

ORDER OF PROCESSING CONTOURS

If the blank has internal contours, it is necessary to cut out the external contour when using WJC (Fig. 1a) after cutting of all internal contours. All options are possible when using laser cutting machines in an analogous situation, for example, cutting the internal circuits of adjacent parts (Fig. 1).

INCISION POINTS

The incision point can be in any part of the contour for the laser machine. This is true for both external and internal contours. Only the end of cuts are recommended for use for the internal contours, as a rule, for WJC, while, for the internal one, on the contrary, any points not located at the end of cuts, for example, the center of the cut, can be so used.

For WJC, if the contour has a combination of acute, obtuse, and right angles, it is recommended not to choose an acute angle as an incision point. If the contour consists of arcs and acute angles, then it is recommended to choose the arc as an incision point.

It is offered to break up the algorithm for constructing the CT path into a number of stages to take into account the restrictions noted above, as well as the features of the choice of incision points and execution of the contours that will allow us to simplify the implementation of

—forming a set of potential incision points;

—generation of the initial path; and

—optimization of the CT path.

The geometrical objects that make up the contour are analyzed at the stage of forming a set of potential incision points (stage 1). The potential points are chosen with a certain step for circles and arcs. In other cases, the potential points are selected according to the rules that have been set out.

A greedy algorithm that constructs the path subsequently and adds a new admissible point at each iteration that is very close to the previously added one is used to generate the initial path (stage 2).

Two metaheuristics, GD and TA, are used at the stage of the CT path optimization (stage 3) that is due to the fact that the best solution receives GD depend-

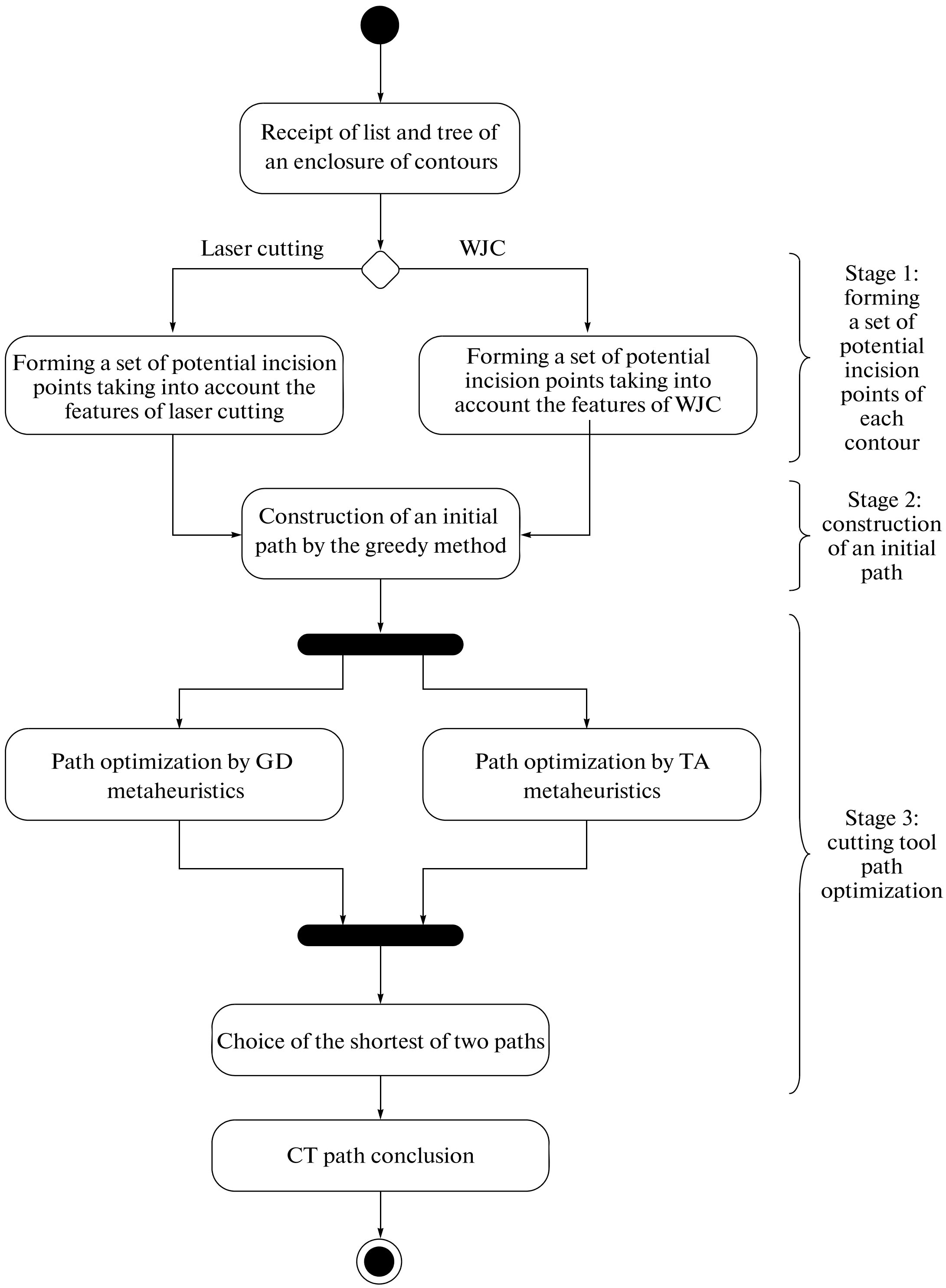

Fig. 2. Generalized scheme of the algorithm for constructing the cutting tool path.

ing on the complexity of the cutting map in some cases, while, in others, it receives TA.

We will note that the input information is a list of all contours, as well as the nesting tree that is necessary for storage of information on the relation of nesting of contours each other. As a result of the algorithm, an admissible order of contour cutting can be determined and the admissible incision point found for each contour.

A generalized scheme of the algorithm is presented in Fig. 2.

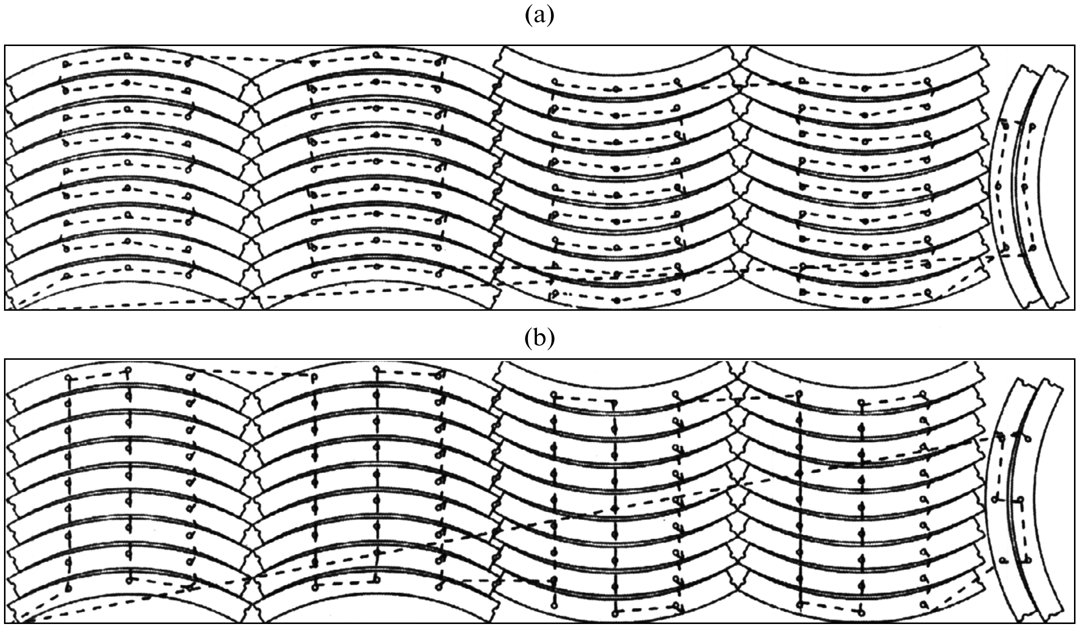

Fig. 3. CT paths for the machines of (a) waterjet and (b) laser cutting.

The suggested approach to determining of the cutting tool path has been introduced into the ITAS NESTING nesting system [4, 5]. Further investigations of the algorithm are conducted for the plans of cutting that are generated in this system.

The first cutting map contains 152 contours (internal and external in the aggregate) and is used to determine the time and the algorithm. The second map contains 18 contours and is used to demonstrate the processing of enclosed contours. Paths are formed for waterjet and laser cutting machines according to the cutting maps.

The average time of forming the CT path for WJC was 3 s on the first map (Fig. 3), while for laser cutting it was 2 s.

It is shown in Fig. 3a that the restrictions are executed for WJC: first, internal contours (circles) are cut out in the blanks, and then external ones were. The incision point of the external contour is on the arch. The length of the idling time is 41646 mm.

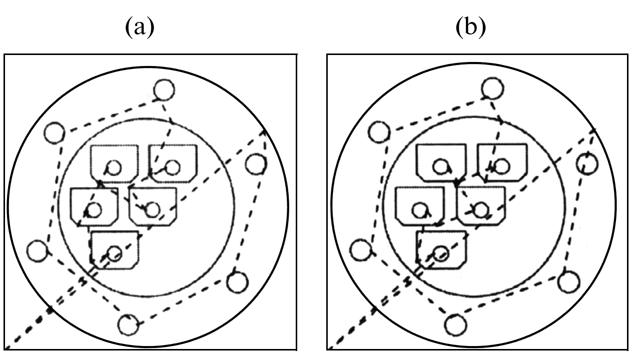

Fig. 4. Processing of enclosed contours by the machines of (a) waterjet and (b) laser cutting.

The mechanism of shape cutting for the laser machine is observed in Fig. 3b. The details are cut out by large groups in the following order: at first, the left internal contours are cut out in the group, then the central ones, and after that the right internal contour and the external contour of the detail. The incision point of the external contour is on the arc. The length of the idling time is 28473 mm.

In the first case, the algorithm works longer as a large number of restrictions are calculated; the length of idling time is more when using WJC, correspondingly. The differences of cutting paths are shown on the second map (Fig. 4) while processing the enclosed contours.

In both cases, at first the parts that are placed inside the ring are cut out, and then the internal contour of the ring, followed in the end by the external one. The difference is that the external contour of the same detail is always cut out for WJC after the internal contour of the enclosed detail (hexagon), and then there takes place transition to the next internal contour of another hexagon. The transition from the internal contour of one hexagon to another internal one, followed by processing of the external contour of the hexagon, is used in laser cutting.

Thus, an energy-efficient algorithm for determining a cutting tool path has been developed that takes into account features of waterjet and laser cutting and reduces power consumption by reducing the length of the CT idling time. Three stages of path construction can be distinguished in the algorithm. Two metaheuristics that allow the features of cutting maps to be considered most thoroughly were used at the stage of optimization. The computational experiment that was carried out showed that the length of the idling time was less than for WJC when using laser cutting; thus, the formation time of the CT path is less for laser cutting than for the waterjet.

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