Generating tool paths for laser cutting machines

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The objective of the tool path problem is to find a tool path that minimizes the total time required to cut all parts from the sheet. In contrast with most research on laser cutting tool paths, this paper does not require that if one starts to cut a contour one needs to finish the contour before moving to a next contour. Obviously, allowing pre-empting significantly increases the number of possible solutions and makes the tool path optimization process more difficult. To our knowledge only Moreira et al. [1] explicitly deal with preempt strategies but they have the extra constraint that the cutter head never stops cutting. In previous work [2], we proposed an IP model and several heuristics to generate tool paths that minimize total distance traveled. A tool path consists of a series of commands telling the laser head from which node to which node it needs to move and where it needs to pierce. If the laser head moves without cutting, the move is called an air move and the time required for an air move is a lot smaller than a cut move. The time required for cut moves is considered to be independent of the chosen tool path. Because of acceleration and deceleration effects the time required for an air move is approximated by a nonlinear function. Every time the laser head needs to start cutting in a new section of the sheet a piercing needs to be made and the time required is dependent on the plate thickness. A pre-cut can be used when while cutting the laser head passes an element where it has to start cutting later. In order to avoid a piercing later, the laser head can make a small cut into that element and then continue cutting. The cost of placing a pre-cut is considerably less than a piercing cost. The objective of the laser cutting tool path problem is to determine a tool path that minimizes the total time required to cut all parts. The total time consists of the sum of the actual cutting time, the time required for all air movements and the time required for piercing the sheet and placing pre-cuts.

This optimization problem can be modeled as a generalized traveling salesman problem (GTSP) [2] with special precedence constraints. These constraints originate from inner-outer contour relations and common cut lines. In [2] an IP model for this problem was presented which can be expanded to include piercing and pre cut costs. Implementations of this program in commercial solvers such as LINDO and CPLEX showed that the calculation times were too large to be of any practical use on the production floor.

We previously showed that an insertion based construction heuristic is able to construct feasible tool paths for laser cutting with considerable shorter paths than those generated by a dedicated sheet metal CAD/CAM software package. A second construction heuristic based on first creating a contour order that guaranteed feasible solutions and then building the tool path was also developed. The tool paths of the second heuristic were of lesser quality but the calculation times were significantly reduced. Three improvement heuristics were able to improve upon these solutions. The first improvement heuristic was a modified dir-opt that optimizes the cut directions for a given element order. The second improvement heuristic was a modified Or-opt move of size 1 and the third improvement heuristic was a 3-opt move where two adjacent sub paths were switched. These three moves were then embedded in a tabu search meta heuristic to allow them to escape local optima. Adding piercing and pre-cut cost evaluations to these heuristics caused considerably longer calculation times and initial results showed that the piercing times are severely dominant over the air movement times. This prompted the development of a new construction heuristic that aims to have only one piercing per *pierce group*. A pierce group is defined as a set of contours that requires at least one piercing (and possibly a set of pre-cuts).

The new pierce group insertion heuristic was tested on a limited number of test cases and was able to find shorter tool paths than those generated by a commercial CAD/CAM software package. The pierce group heuristic was found to be 0-34% and 0-4% better than the commercial software package for respectively thin and thick plates. When the improvement algorithms are applied to this heuristic for a period of five seconds, tool paths 0-42% and 0-5.3% better than the commercial package for respectively thin and thick plates can be found. The biggest improvements in solution quality were found in nests with large pierce groups and small inter pierce group distances.

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