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About some types of constraints in problems of routing

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Many routing problems arising in dierent applications can be interpreted as a discrete optimization problem with additional constraints. The latter include generalized travelling salesman problem (GTSP), to which task of tool routing for CNC thermal cutting machines is sometimes reduced. Technological requirements bound to thermal elds distribution during cutting process are of great importance when developing algorithms for this task solution. These requirements give rise to some specic constraints for GTSP. This paper provides a mathematical formulation for the problem of thermal elds calculating during metal sheet thermal cutting. Corresponding algorithm with its programmatic implementation is considered. The mathematical model allowing taking such constraints into account considering other routing problems is discussed either.

Keywords: thermal cutting; discrete optimization; toolpath routing; technological constraints; dynamic programming; thermal deformations

1. Introduction

In various industries many parts are produced from sheet materials by CNC equipment. Such kind of equipment includes, for instance, machines for laser, plasma, gas, and water-jet cutting. Special software (Computer-Aided Manufacturing, CAM systems) provides an automation of development of NC (numerical control) programs. Generating of NC programs is next step after nesting that is positioning parts onto sheet material. Optimization of sheet utilization reduces the cost of sheet material used for parts producing. The nesting problem is not considered in this study. The control programs contain information about tool path for CNC machine and some technological commands. Optimization of tool path reduces time and cost of cutting process. First classification of problem was conducted by Hoeft and Palekar (1997). Tool path problems are usually divided into 4 classes depending on cutting technique and its parameters (see, for example, Dewil et al. (2015)):

(1) *Continuous Cutting Problem (CCP).*
(2) *Endpoint Cutting Problem (ECP).*
(3) *Intermittent Cutting Problem (ICP).*
(4) *Generalized Traveling Salesman Problem (GTSP).*

Petunin (2015) offered new classification of cutting techniques and described one more class of problem: *Segment Continuous Cutting Problem (SCCP).*

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1.1 *Tool Path Components*

The tool path contains the following components (see Fig.1):

- Pierce points (piercings);
- Points of switching the tool off;
- Tool trajectory from piercing up to point of switching the tool off;
- Lead-in (tool trajectory from piercing up to the entry point on the equidistant contours);
- Lead-out (tool trajectory from exit point on equidistant contour up to tool switching off point);
- Airtime motions (linear movement from tool switching off point up to the next piercing).

1.2 *Cutting Techniques*

2. Formal Definition of Tool Path

Finally, the tool path is defined by a tuple:

$$ROUTE =< S_1, S_2, \ldots S_K, i_1, i_2, \ldots i_K > \tag{1}$$

During development of NC programs for CNC sheet metal cutting machines the problems of tool path optimization arise. As optimization criteria in these problems the parameters of cutting time t_{cut} and cost F_{cost} are considered. They are calculated by following formulas:

$$t_{cut} = L_{on} \div V_{on} + L_{off} \div V_{off} + N_{pt} \cdot t_{pt} \tag{2}$$

$$F_{cost} = L_{on} \cdot C_{on} + L_{off} \cdot V_{off} + N_{pt} \cdot C_{pt} \tag{3}$$

Here L_{off} is length of idling tool path; L_{on} is length of working tool path; V_{off} is speed of idling tool path; V_{on} is speed of the working tool path; C_{off} is cost of idling tool path unit; C_{on} is cost of working tool path unit; N_{pt} is numbers of piercing; t_{pt} is time of one piercing; C_{pt} is cost of one piercing.

Objective functions (2) and (3) for the tool path depend on elements of tuple (1). Let us consider technological constraints on tuple $< M_1, M_1^*, \ldots, M_K, M_K^*, i_1, \ldots, i_K >$ elements.

3. Tool Path Constraints Formalization

3.1 *Precedence Constraint*

3.2 *Piercing Coordinates Constraints*

See Fig. 1

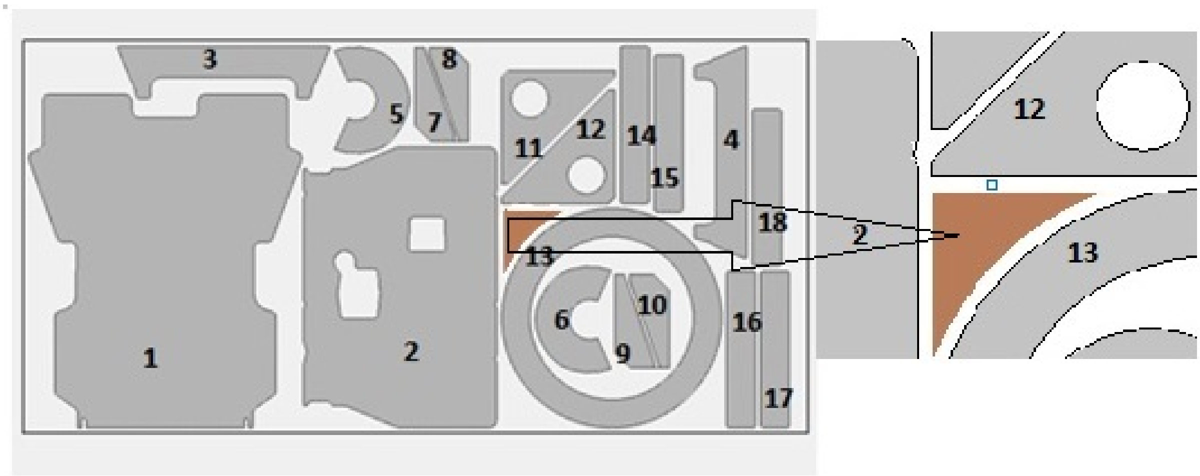
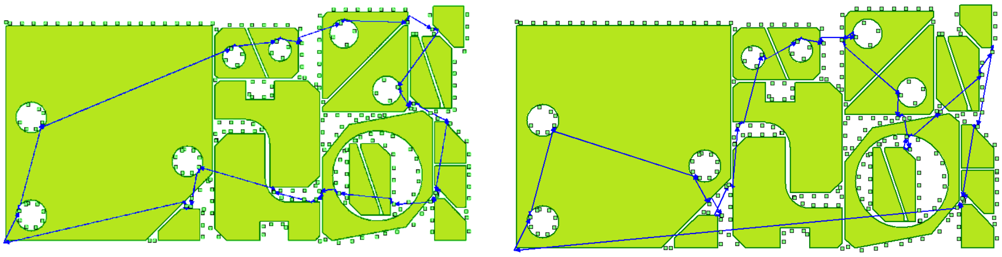


Figure 1. Feasible piercing area is marked with brown color.



(a) Exact SCCP solution.

(b) Solution with thermal cutting constraints.

Figure 2. Results of tool path optimizations.

3.3 *Part Hardness Rule*

3.3.1 Formalization of Part Hardness Rule

3.3.2 Thermal Distribution Calculations

3.4 *Sheet Hardness Rules*

4. Discrete Optimization Algorithms

See Fig. 2...

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References

Dewil, R., P. Vansteenwegen, D. Cattrysse, M. Laguna, and T. Vossen. 2015. "An improvement heuristic framework for the laser cutting tool path problem." *International Journal of Production Research* 53 (6):

1761–1776.

Hoeft, J., and U.S. Palekar. 1997. "Heuristics for the plate-cutting traveling salesman problem." *IIE Transactions (Institute of Industrial Engineers)* 29 (9): 719–731.

Petunin, A.A. 2015. "Modeling of tool path for the CNC sheet cutting machines." Vol. 1690. DOI: 10.1063/1.4936740.