Automated Tool Selection for Computer-Aided Process Planning in Sheet Metal Bending

J. R. Duflou[1] (2), T. H. M. Nguyen[1], J.-P. Kruth[1] (1), D. Cattrysse[2]

[1] Department of Mechanical Engineering, [2] Centre for Industrial Management

Katholieke Universiteit Leuven, Celestijnenlaan 300, 3001 Leuven, Belgium

Abstract

Bend sequencing and tool selection have long been the main hurdles for achieving automatic process planning for sheet metal bending. In this unique process, the complex shape and position transitions of workpieces make it hard to obtain a collision-free operation plan. The time-consuming involvement of human experts is often required to solve more complex problems. This paper presents a tool selection methodology to be integrated in the automatic bend sequencing system discussed in previous work, therefore contributing to fully automated process planning for bent sheet metal parts. Both the described selection strategy and the related algorithms have been implemented in an industrial software package. The results presented in this paper, as illustrated by a number of case studies, demonstrate that automatic process planning for sheet metal bending is feasible and that the developed system provides well-optimised solutions with a reasonable time complexity.

Keywords:

CAPP, Tooling, Bending

1 INTRODUCTION

Sheet metal bending using press brakes is a flexible process for parts formed from metal sheets by linear bends. Process planning for this process includes two interlacing aspects, namely bend sequencing and tool selection. The first aspect tackles the method to sequence all the bending operations in order to avoid collisions between the part being bent and other objects in the production environment. Efforts to automate this step resulted in computer aided solutions, including heuristic search techniques based on a rule set for collision avoidance [1, 2, 3], and on tolerance specifications [4, 5]. However, such approaches often rely on interactive tool selection or do not take tool selection into consideration. Consequently, if the tools are not strategically selected by experienced process planners, feasible solutions often cannot be assured.

In parallel, tool selection has been mentioned or partially dealt with by researchers in the field [6, 7, 8, 9]. In consideration of the macro technological aspects, an expert system was built using LISP language to interactively aid process planners in choosing the right sheet metal process and tooling type [7, 9]. In a more detailed perspective, existing automatic tool selection strategies [6, 8] often start from a predetermined bending sequence. Such strategies frequently result in expensive construction of specially tailored tools, which are needed to avoid obvious collisions that result from the chosen bend sequence. Traditionally, the approach chosen to eliminate the need for expert-based tool selection is a combinatorial search problem formulation for an open selection [2, 6]. Under such regime, solutions for complex parts cannot be identified within a limited time span.

This research presents a methodology to automatically identify feasible and well-optimised tool sets based on part descriptions and available production environments. The method can be integrated in and is complementary to existing bend sequencing procedures. Feasible tools are selected based on technological and geometric considerations. The latter is implemented into two steps: preselection based on the final part description and refined selection based on intermediate stages of the workpiece during bending. Additionally, common guidelines for optimal tool usage are translated into optimisation strategies, ready to be used in different process planning phases. The methodology presented is demonstrated by an industrial software implementation. Test results from benchmark parts support the conclusions on the feasibility and performance of the method.

2 TOOL SELECTION METHODOLOGY

Tool selection methods for production processes typically consist of procedures to convert product specifications into selection criteria for related parameters, in order to identify the relevant machines and tools. Moreover, where a minimal production resource is desired, optimisation algorithms are usually applied. These two aspects are collectively handled in the feasible tool selection and optimisation procedures for bent sheet metal products as explained below.

2.1 Feasible tool selection

Technological considerations

Similar to other production processes, tools selected for sheet metal bending should meet the technological constraints imposed by the part to be produced in order to assure technical feasibility and to provide the appropriate bend line quality as determined by the design specifications. The relations between these two aspects are found scattered in literature in either tabulated format or as simple rules of thumb. Based on these relations, three subsequent steps are distinguished in this study to preselect tools under technological considerations.

The initial step is to select the bending technique, limited to air bending and bottoming on press brakes. The choice to be made depends on the accuracy, and the bend features required. The information of the bend angle accuracy is converted into requirements for the bending techniques, and considerations for available in-process measuring and adaptive control equipment. Bend lines characterised by special features, such as hemmed edges, are immediately provided with appropriate special tooling in this step.

The second step is to select the machine class, i.e. the range of setup length, tonnage, and gauging requirements. The force required to make the longest bend with the material and bending technique selected is calculated in order to specify the tonnage of the machine to be used. Bend lines with no parallel gauging solution imply selection of press brakes with independent back gauges.

The third step is to select the tool class compatible with the chosen bending techniques and machine classes. Decisions are made based on the required force for the bend features as well as their shapes. This step takes as input various parameters of the part, such as the sheet thickness, material properties of the sheet, and geometric characteristics of the bend features to be performed, including the required internal radius, the bend angle, and the minimum bend-flange width.

Geometric considerations

Studies [2, 3] show that most collisions in bending occur between bent parts and tools, especially when final shapes are nearly achieved. Besides altering the bend sequence, pragmatic solutions to most of those situations are appropriate tool selections by process planners. Therefore, in addition to complying with the technological considerations, tool selection for a bent part must firstly take into account its final shape, and secondly allow necessary adjustments based on its intermediate shapes.

As a result, at the strategic level geometric tool selection can be divided into two phases. The first phase is called the preselection phase, which eliminates obvious collision-prone tool shapes based on the envisaged part shape. Subsequently, bend lines are assigned with corresponding preselected tools, providing a favourable initiation for the bend sequencing step, since it efficiently reduces the number of collisions encountered while searching for a collision-free bend sequence [2]. The second phase is called the refined selection phase, which selects the tools based on the collisions encountered by the part in its intermediate stages during bend sequencing. If the tools are already preselected, refined selection only adjusts the preselected tools to suit the stricter conditions imposed by the collisions encountered.

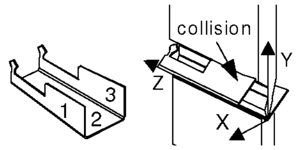
At the tactical level, an algorithm for linking the geometric aspects between bent parts and bending tools has been developed. Instead of direct matching between available tool types and part shapes, which is not applicable due to the continuous shape transitions of the bent parts [2], a generic rule set has been established in this study to link possible collision patterns with geometric features, representing the collision avoidance capability of tools. To facilitate the application of these rules, in this study each collision pattern is defined by a combination of the following factors: the machine component or tool involved in the collision, the collision flange of the part being bent, the direction from which the collision flange comes, and the bending phase in which the collision occurs. The collision patterns are identified in the preselection phase by analysing the final part; while in the refined selection phase, they are directly identified from the collision detection module activated during bend sequencing [2]. The utilisation of the information encapsulated in collision patterns, instead of pure tool and part geometries, allows an efficient identification of requirements for tool selection by a selective application of rules, a fast estimation of actual collision, and therefore a handy production of criteria for geometric tool selection.

Firstly, the rules qualitatively specify the following feature requirements on tools based on the collision component identified in the collision pattern. For punches, (1) a greater height is required for collisions with the machine ram, (2) a horn tool - for collisions at the side, (3) a gooseneck feature - for collisions along the bend line, (4) tool windowing - for collisions partially along the bend line where no gooseneck tool can be found because the collision flange protrudes too far. Similarly, changing of the die features can give solutions, such as (1) a die with a thinner body width - for collisions with the die, (2) a greater die height - for collisions with the machine table.

Secondly, the range of values to be met by the geometric features specified by the rules above is quantitatively specified from the collision patterns. For each of the patterns encountered, the respective collision flange(s) are clipped based on the collision component's bounding box and the collision direction in order to define the coordinates of the actual collision ranges in 3D.

Afterwards, the derivation of logical constraints for tool selection combines the logical part from the triggered rules and the value range obtained from processing the collision flanges. In this way, appropriate sets of quantified rules are combined for all collision patterns foreseen per bend line. An example of the procedure of tool selection based on the analysis of collision patterns is shown in Figure 1, where the tool parameters used in the constraints generated are explained in Figure 3.

(a) Collision patterns:
Collision with punch from side +/- 1 of flange 1 and 3 after bend



(b) Actual interference ranges:
Side-1 Lower Bound X = -10.0000, Y = 46.3887, Z = 0
Upper Bound X = -2.1213, Y = 54.9744, Z = 97
Side+1 Lower Bound X = 2.1213 , Y = 46.3887, Z = 0
Upper Bound X = 10.0000, Y = 54.9744, Z =97

(c) Rule: *Choose a gooseneck punch*

(d) Logical constraints and corresponding tools selected for the collisions foreseen:
GOOSENECK PUNCH
{ [(C-side = -1) AND (C-depth ≥ -2.1213)
AND (C-low ≤ 46.3887)AND (C-high ≥ 54.9744)]
OR
[(C-side = +1) AND (C-depth ≤ 2.1213)
AND (C-low ≤ 46.3887)AND (C-high ≥ 54.9744)]}

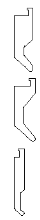


Figure 1: Tool selection based on collision pattern.

In assistance to the application of the rules described above, a thorough analysis on the important three-dimensional features of parts and tools has been accomplished in this research to quickly identify potential collision patterns from bent parts and the collision avoidance capability of tools for bending.

On the one hand, analysing three-dimensional part features shows that there are often a number of difficult partitions, commonly called local details, residing in the designs to be produced. Such local details often cause (a combination of) collision patterns, requiring precise tool selection. The definitions and properties of the details identified together with their corresponding collision patterns are shown in Figure 2. If graph representations are used for bent parts and the local details, where nodes and arcs correspond to bend flanges and bend lines respectively, the *pattern graphs* representing the details can be matched with the *target graphs* representing parts in polynomial time [10]. Therefore, all the local details can be detected from bent parts, facilitating the identification of their respective collision patterns.

On the other hand, aiming at characterising the collision avoidance capability offered by individual tools in a uniform way, despite their numerous commercial coding and shape variety, a system capable of extracting the geometric parameters representing the collision avoidance capability of tools has been developed. Among all the intrinsic shape features, a vital collision avoidance capability of a punch has been identified in this study and is represented by a typical shape feature, which is referred