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Reducing the number of setups for CNC punch presses

S. Zamiri Marvizadeh [a], F.F. Choobineh [b,*]

[a] Department of Industrial and Management Systems Engineering, University of Nebraska-Lincoln, NE 68588, USA
[b] Department of Electrical Engineering, University of Nebraska-Lincoln, NE 68588, USA

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ABSTRACT

Large computer numerical control (CNC) punch presses are widely used for punching holes in heavy gage sheet metals. The turret of such presses has limited tool capacity, and any tool changes require dismantling the turret. Dismantling and reloading the turret generally takes several hours and is the dominant element of the total flow time for a batch of sheet metals. Reducing the turret setup time requires judicious grouping of the required tool set. We formulated an integer program to obtain the minimum number of setups. However, since the problem is nondeterministic polynomial-time hard (NP-hard), we offer three heuristics to solve the problem. We compare solutions obtained from the three heuristics with their respective optimal solutions using three simulated data sets and an industrial data set.

1. Introduction

Sheet metal fabricators use computer numerical control (CNC) machines for bending, sheering and/or punching operations. Their application in medium to high throughput production is widespread because of their flexibility in satisfying the needs of different products. A particular punched hole is created with a specific tool. Since a sheet metal part generally requires more than one punched hole, multiple tools are needed to produce a sheet metal part to specifications. Here we focus on setup reduction for CNC machines that are configured to punch holes of different sizes and shapes on sheet metals.

During a production planning horizon, the nonidle time of a CNC punch press consists of punch times (operation times), sequence times (times needed to move from one punch to the next in a sequence of punches) and tool setup times (placing tools on the CNC turret or tool magazine). Operation (punch) times are very short and generally negligible relative to sequence and setup times. Sequence and setup times are a function of the number of punches required for a part and the size and configuration of the punch press. Sequence time could be significant if a part requires more than ten punches and cannot be ignored since it impacts the makespan. Setup time for a heavy punch press is the dominate factor in calculating the makespan, and its impact is much more significant than the sequence time.

Heavy punch presses are used for punching holes in heavy gage sheet metals, and their tools are mounted on a turret. A tool set mounted on the turret may need to be changed when the tool set does not satisfy the tool requirements of parts scheduled on the punch press. Performing a tool change (turret setup) requires dismantling the turret, and exchanging some or all tools on the turret before it is reloaded into the punch press. Dismantling the turret requires a fixed amount of time; however, the time taken to exchange tools varies by the number of exchanges. If the variation between the numbers of exchanges among setups is small, then exchange dependent setup time may be viewed almost fixed and combined with the dismantling time to obtain the total setup time.

Turret setup generally requires five to seven hours, and the variation depends on the number of tool exchanges. A punch takes less than a minute to perform, and the time between two punches is about one minute. In our application variation of tool exchange among setups is low, and we only concern ourselves with the number of setup instances. Since setup time is significantly larger than both punch time and the time between two punches, setup reduction for heavy punch presses is the focus of this paper.

This problem was brought to us by a local industry that makes outdoor signal switching cabinets for communication industries. Specifically, the industrial application of our concern involves an Amada punch press with a round turret, as shown in Fig. 1. This turret has 56 holes of 7 types with the hole capacity vector of {16 8 12 12 4 2 2}. Each hole is referred to as a station in CNC programmer parlance. Each station has a particular address (number) that is used in the CNC program. The stations are capable of handling nominal punch sizes ranging from ½ to 4½ inches in diameter. The slanted tool can only be placed on the outside stations. Inserting tools into each station requires dismantling the turret. The scheduling (planning) horizon for this punch press is two days. Table A1 in Appendix shows a typical two-day schedule for the punch press that consists of 35 part types requiring 100 tool types. Table A2 shows the tools' compatibility with the turret holes.

* Corresponding author. Tel.: +1 402 472 1388; fax: +1 402 472 8948.
E-mail address: fchoobineh@nebraska.edu (F.F. Choobineh).

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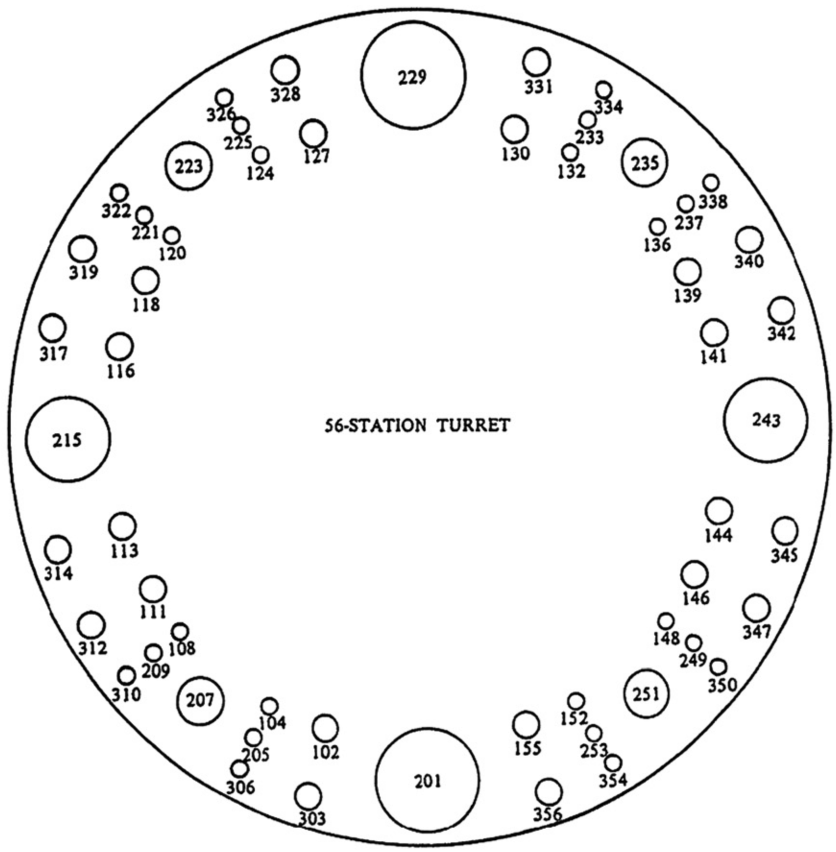

Punch Type	Nominal Punch Size	Standard Punch Size	Number of Stations Available
A	1/2″	1.6- 12.7 mm dia.*	24 (8)**
B	1-1/4″	12.8- 31.7 mm dia.	24 (12)
C	2″	31.8- 50.8 mm dia.	4 (4)
D	3-1/2″	50.9- 88.9 mm dia.	2 (2)
E	4-1/2″	89.0-114.3 mm dia.	2 (2)

* The punches are available in gradations of 0.1 mm dia.
** The numerals in parentheses indicate the number of stations which can accept shaped punches.

Fig. 1. A rendition of a 56-hole Amada punch press turret with seven hole types.

The remainder of this paper is organized as follows. In Section 2, we present a brief review of prior work. In Section 3, we provide a mathematical presentation of the problem and formulate an integer program to obtain the optimal solution. Since the problem is NP-hard, we offer three heuristics of varying complexity in Section 4; and in Section 5, we investigate the performance of the proposed heuristics. Finally, conclusions are given in Section 6.

2. Prior work

Operation sequencing and tool-switch scheduling are the main issues in production planning for CNC punch presses. Operation sequencing minimizes the tool and part movements during the CNC operation and can be considered as a special case of the traveling salesman problem. Several authors, such as Walas and Askin [1], Chauney et al. [2], Ssemakula and Rangachar [3] and Roychoudhury and Muth [4], have proposed various methods and techniques for CNC punch press operation sequencing. Tool-switch scheduling minimizes the number of tools/parts partitions and can be viewed as a batching problem. Since a tool/part batching problem is NP-hard, heuristic algorithms have been offered for obtaining reasonable solutions (e.g., see Tang and Zhao [5], Tang and Wang [6] and Gribkovskaia et al. [7]).

The literature on tool switching for CNC punch presses may be divided into those where the objective is (a) minimizing the number of tool switches or (b) minimizing the number of tool switching instances. The distinction between the two objectives is dictated by the amount of setup time needed to start the tool-switching task. Generally, replacing tools on a tool magazine