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Efficient approaches for furnace loading of cylindrical parts

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ABSTRACT

This paper addresses the heat treatment operation in a manufacturing plant that produces different types of cylindrical parts. The immediate prior process to heat treatment is furnace-loading, where parts are loaded into baskets. The furnace-loading process is complex and involves issues relating to geometry, and heterogeneity in the parts and in their processing requirements. Currently, furnace-loading is accomplished by operator ingenuity; consequently, the parts loaded in heat treatment often do not use furnace capacity adequately. Efficiency in furnace operation can be achieved by improving basket utilization, which is determined by the furnace-loading process. This paper describes the development of integer and mixed integer LP models for 3D loading of cylindrical parts into furnace baskets. The models consider the exact location of parts to be loaded on the basket and incorporate three models with different objectives; the first addresses the nesting of parts within one another, the second addresses the number of basket layers used, and the third addresses the number of baskets used.

1. Introduction

This research addresses a loading problem of cylindrical parts (bearings) in a manufacturing company. In the heat treatment operation, a batch of part blanks is placed into a rectangular basket and then the basket is processed in the furnace, a batch machine used for the heat treatment operation, in order to impart specified case thickness. Prior to heat treatment operation there are two operations for bearings, ring rolling and turning, and the subsequent operation to heat treatment is the finishing operation which includes grinding, turning and assembly. Often the basket-loading process determines the throughput of the furnace system.

In the process of loading bearings into baskets, a mix of different sizes of bearings is placed in baskets to form layers which are separated by a perforated screens placed on top of the parts. This process is complex and involves issues relating to geometry, and heterogeneity in the parts and their processing requirements. Considering the part external and internal diameters, height, and processing required in the furnace (termed "recipe"), several rules must be followed in loading a basket: (1) Material type: All parts in a basket must be made from the same material; (2) Part height: Parts in a layer must have the same height; (3) Recipe: There are a total of 30 recipes, 15 for each material type. These recipes are characterized by a cycle time, a temperature profile, and a profile for the rate of carbon injection. In a single basket, parts with recipe numbers within a two-number range are permissible; for example, parts with recipe numbers 3 and 4 or 4 and 5 are permitted to be loaded into the same basket; and (4) Nesting: Parts can be nested in a layer; "nesting" implies putting parts within the

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internal diameter of another part. If the internal diameter of the outer part is x millimeters then the external diameter of the inner part must be a maximum of $(x - 50)$ millimeters, to keep 25 mm clearance between the parts.

Currently, the planning department develops a production plan under a ''push'' strategy approach. The plan assigns priorities to different orders and sequences the orders for processing. Based on this plan the shop-floor picks up orders for processing. Such a plan does not take into account the rules to be adhered to in loading parts for the heat treatment operation. Consequently, the heat treatment department could become a bottleneck in the production process. Furthermore, the loading process is implemented ingenuity by operators such that the batches loaded for heat treatment do not adequately utilize basket and furnace capacities. Thus, an efficient tool is needed to produce three-dimensional loading models that optimally utilize the basket capacity which is critical in achieving furnace throughput maximization/improvement.

The primary objective of this paper is to optimize furnace operations by minimizing the unutilized capacity of the baskets used in the heat treatment operation of the cylindrical parts.

2. Review of the packing problem

In the context of this research, it is relevant to review published research on the packing problem. The problem of packing items onto pallets or into containers in an efficient manner can be computationally complex [1]. Existing approaches to pallet/container loading problems usually apply to a specific class of problem encountered in practice, but there are many scenarios for which no adequate methodologies currently exist. The problem of positioning/packing/loading small items inside bigger spaces which is usually referred to as the ''pallet packing/loading problem'' arises in several industrial activities. The primary issue in pallet packing has been that of maximizing the area of the pallet used [2]. The general pallet-packing problem can be viewed as a two-dimensional cutting stock problem. The objective is to minimize the waste [3]. Ram [2] provided a survey of research relating to considerations in pallet packing, the models and solution procedures used in pallet packing, and implementation of these approaches in palletization stations. It is generally known that the effectiveness of these approaches can be quite an important economical factor for the success of these industries. Chen et al. [3] developed a mathematical model for palletization problem for boxes that are of varying dimensions with the objective of placing a given set of cartons on minimal number of uniform pallets. The model was guaranteed to lead to an optimal solution.

The three-dimensional packing problem most frequently consists in finding efficient positioning patterns of identical (rectangular or cylindrical) objects on a rectangular base (pallet), where the vertical orientation of the objects is determined by practical constraints. These patterns are repeated for each layer stacked on the pallet. Therefore, the standardization of the object's vertical dimension supports the reduction of the dimensionality of the problem; Dowsland [4] applied the knowledge of the two-dimensional pallet loading problem to the three-dimensional loading problem to maximize the number of equal-sized cartons inside a container without overlapping. When boxes have different base dimensions; some interesting heuristics for pallet loading were considered by Han et al. [5], Abdou and Yang [6], and Abdou and Elmasry [7].

The ''cylinder packing problem'' is basically concerned with the densest packing of identical circles (cylinders base) inside a rectangle (the pallet). Several papers, have investigated the problem of packing pipes [1], reels and cylinders into containers. Although not able to solve the three-dimensional case the concepts incorporated in these heuristics could be used in solving various aspects of the cylinder packing problem. Several studies addressed the problem of packing circles of the same size into a rectangle including Dowsland [8], and Fraser and George [9]. They depended on fast heuristic algorithms for more complex cases to generate approximate solutions. Isermann [10] proposed some heuristic techniques for packing identical circles in homogeneous patterns developed geometrically, restricting its attention to problems where the product surface area is smaller than the rectangle.

A few authors have studied the problem of packing circles of different sizes into a rectangle [11]. Fraser and George [9] discussed loading reels inside a container in the context of a paper industry, where the relative position circle is chosen among a set of easily stowed pre-defined patterns. Most recently published research also considers the problem of packing circles of different sizes inside a rectangle. Hifi et al. [12] developed a simulated annealing based approach to solve the generic ''circular cutting problem''. Stoyan and Yaskov [13] proposed a solution method based on a branch-and-bound algorithm and a reduced gradient method to solve a mathematical model of the problem of placement of rectangles and circles in a larger rectangle. George et al. [11] discussed several heuristic approaches and included stability considerations in the context of loading pipes of different diameters inside a container. They also proposed a mixed integer non-linear formulation for the problem of fitting different circles inside a rectangle, which is difficult to solve, even for a small number of pieces, by the current general purpose mixed integer non-linear optimization software packages. Zhang et al. [14] studied the problem of packing different-sized circles into a rectangular container. They formulated this problem as a nonlinear optimization problem and developed a heuristic simulated annealing algorithm for solving this problem. Huang et al. [15] proposed two new heuristics to pack unequal circles into a two-dimensional circular container. The first one, denoted by A1.0, is a basic heuristic which selects the next circle to place according to the maximal hole degree rule. The second one, denoted by A1.5, uses a self look-ahead strategy to improve A1.0.

Babu and Babu [16] proposed a hybrid approach, employing both genetic and heuristic algorithms, for nesting of different rectangular parts in multiple rectangular sheets with the objective of utilizing the sheet material effectively. The proposed genetic approach gave the best sequence of sheets and parts to generate an effective nested pattern with a heuristic algorithm. The heuristic approach arranges each of the parts in the bottom-left-most position of the sheet(s) by considering