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Technical paper

STEP-NC compliant approach for setup planning problem on multiple fixture pallets

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ABSTRACT

Manufacturing system configuration is a broad problem that involves various topics concerning workpiece, cutters, fixture and machine. This paper presents an approach to solve the setup planning problem on machining centres based on a STEP-NC compliant data structure. The aim of this approach is to shorten the time required for the process planning activity by automating some time-consuming steps without compromising the solution accuracy. In the proposed approach, a CAM software tool is employed to associate the geometric and technological data regarding the product. Using the proposed data structure, a method is proposed for solving the setup planning problem based on mathematical programming. The developed approach has been tested on a real case.

1. Introduction

The setup planning problem in manufacturing [1] represents a critical link between general process planning and operation planning and consists of determining the various positioning of the workpiece in 3D space that are required to perform machining of all its relevant features. This problem also addresses the grouping of features into setup in their proper sequences, selecting a datum for each setup and choosing the appropriate tools and fixtures. Setup planning plays a key role in manufacturing system configuration because it influences both production costs and product quality. Each change in the orientation (setup) of the workpiece requires un-mounting and re-mounting of the workpieces on the fixture, which creates additional costs in terms of time and potential losses of machining precision and manufacturing quality. Indeed, re-mounting of a workpiece can cause a shift of machining reference points in terms of distances or rotations, which can affect the machining precision, especially with respect to error propagation. After the setup planning phase, the pallet configuration problem must be addressed. The number and the mix of pieces that must be applied and clamped on the fixturing device of the pallet as well as their disposition and setup must be calculated on the basis of different criteria and objectives, e.g., minimising the unproductive time (the so-called "air time") when processing the pallet, maximising the pallet face saturation, and ensuring a certain level of stability and accessibility of the workpieces during machining, among others. The complexity of the problem increases when multiple fixture pallets are considered. Indeed, it is not uncommon for a part to be mounted with different orientations (setups) on the same pallet, and several product types in different setups can be clamped on the same pallet.

Setup planning and pallet configuration activities (and system configuration in general) are time consuming and expensive because many economic and technological issues must be considered. Therefore, there is the need of a support software tool that can render the configuration procedure more efficient via reduction of the time required to obtain a good solution and identification of a more effective solution to increase the possibility of using the best configuration [1,2].

This paper presents an approach for the resolution of setup planning problem on multiple fixture pallets based on a STEP-NC compliant data structure. The proposed method allows the determination of a near optimal setup plan when more than one part can be mounted on the same pallet and provides a configuration solution for the subsequent fixture pallet. This approach addresses the machining of prismatic features (the so-called "2½D features" [2]) on prismatic and axial-symmetric parts. The developed STEP-NC oriented data structure presents a product/process/system scheme that aids in management of the information required for setup planning. The proposed approach for problem resolution is based on

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mathematical programming logic. The potential advantages of this approach consist of its capability to scan all feasible solutions and to find one or more solutions that are optimal relative to a specific optimisation goal. Moreover, this method treats the entire problem in a single approach to avoid the introduction of problem splitting constraints that could yield sub-optimal solutions. In addition, the proposed approach is also intended to provide the best solution for manufacturing system configuration problems characterised by a high level of complexity and to shorten the time required for the process planning activity by automating some time-consuming steps without compromising solution accuracy.

The paper is organised as follows. The following section presents a literature review of the setup planning problem. The third section offers the problem statement, detailed assumptions and an application context. The fourth section defines the STEP-NC oriented data structure on which the proposed approach is based. The fifth section provides a detailed description of the various steps of the approach for resolution of the considered problem. The sixth section presents the validation of the approach based on a real case. Finally, the last section summarises conclusions and indicates certain directions for further research.

2. Literature review on setup planning

Setup planning is commonly considered as a critical phase of the process planning process, i.e., the design process in which all activities needed to transform raw parts into finished parts are planned. A large portion of the existing papers on setup planning is focused on 3-axes CNC machines.

Sarma and Wright [3] proposed certain guidelines for setup planning, followed by work from many other authors. According to the theory, the first phase of process planning (for a 3-axes machine) is recognition of all features that must be realised on the workpiece. After this phase, a tool direction approach is chosen for those features that can be approached from more than one direction. The features are clustered in setups, which are subsequently organised into a sequence. Finally, operations in the same setup are sequenced as well. This approach implies the a priori definition of the tool direction adopted for each feature, which could create a vicious circle, because the choice of the tool direction impacts the operation sequence, which could be optimised by changing the tool direction approaches for certain features. Backtracking loops are normally introduced to optimise on a case-by-case basis in non-optimal situations. The Quine-McCluskey algorithm has been proposed for selection of the optimal tool direction approach in [2] and [4,5].

In [4] and [6], the problem of managing tolerance constraints during setup planning is addressed, while in [7] both precedence and tolerance constraints are considered, and feature-direction coupling is accomplished by forcing two features related by tolerances to be assigned to the same working direction whenever possible. The most common technique adopted for the operation and setup sequencing problem is graph theory [3–5,8] with particular reference to oriented graphs and hybrid graphs because they adapt well to constrained sequencing problems in which the production time must be minimised. In [9], an optimisation approach is proposed based on simulated annealing and is aimed at minimising the production costs. Other papers propose artificial intelligence techniques for resolution of the setup planning problem: [7] and [10] use fuzzy logic to define the direction for each feature, while sequencing problem is approached using neural networks by the interpretation of the sequencing problem as a Travelling Salesman Problem (TSP). In [11], the TSP interpretation is further complicated by the consideration of a "constraint-based TSP". In [12] and [13], different neural networks are adopted to choose the working direction and tools for each operation, while the setup planning problem is tackled using a rule engine. Finally, other papers apply meta-heuristics, i.e., simulated annealing methods, to tackle this problem. An interesting summary of these papers can be found in [14].

A problem commonly encountered in these contributions is the fact that the choice of the machining direction for each feature is made prior to the setup planning phase and is not reconsidered later on, causing a possible over-constraint of the solution. Therefore, most of the approaches are efficient, but the identified solution cannot be guarantee to be optimal. Additionally, most of the approaches are developed for 3-axes machines, but the management of the same problem on 4-axes machines introduces a number of additional considerations, i.e., feature visibility issues on the pallet and direction allocation for the features, which make the problem much more complicated.

The reviewed papers, as most of the setup planning research, have been addressed in the context of Computer Aided Process Planning (CAPP) and have avoided any considerations about the fixture. Fixture design activities usually follow the setup planning phase and impose other feasibility constraints on the solution. A portion of setup planning literature stresses fixture planning. Sakurai [15] proposed a method based on feedback from the fixture design phase. A setup is associated with each feature's working direction, and for each setup, heuristics are applied to identify the best locating surface. The locating and clamping positions are checked against a set of physical requirements and heuristics to verify whether a specific setup is fixturable. This feedback is subsequently used to decide whether setup regrouping is required. Similar approaches have been documented in [16,17]. Other contributions [18,19] focus only on fixture planning using geometrical and cinematic analysis. Given the state of the art, the basic concept of the current paper is also an attempt at including certain aspects of fixture planning into the setup planning phase. Fixturing constraints are considered during the setup generation in a holistic approach, thus avoiding data feedback and problem splitting that could yield sub-optimal solutions.

3. Problem statement

In this paper, setup planning and pallet configuration problems are taken into account, and attention is focused on the setup planning of mechanical prismatic workpieces clamped onto a pallet via the use of modular holding fixtures. The pallet configuration is optimised for one single product type also considering to put together different setups of the same workpiece on different faces of the same pallet. Tombstone type pallets are taken into account (see Fig. 2). The proposed method is devised for 4-axis CNC machining centres with rotary table (Fig. 1).

The problem addresses a group of workpieces characterised by a number of geometric features. Each geometric feature is associated with one or more machining operations. Each operation on a certain feature requires the creation of a unique machining workingstep [20] that represents the match of a feature with a single operation. In the formulation of the problem, we chose to consider alternative workingsteps: each feature, if it is not characterised by a complex geometry, can admit more than one Tool Approach Direction (TAD) [8] (e.g., for the slot in Fig. 3). For each of these different directions, and thus, the choice of machining direction for the feature is carried out via selection of the corresponding machining workingstep. All alternative workingsteps are mutually exclusive such that only one can be chosen within a group of alternatives.

Papers in the literature do not agree on the choice of the reference object for the problem. Certain papers use the generic term "operation", with a meaning different from the STEP interpretation