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ISO 14649-based nonlinear process planning implementation for complex machining

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Abstract

Increasing attention is being paid to complete machining, i.e., machining of the whole part in a single machine tool, in the metal working industry. For this purpose, complex machine tools equipped with machining components, such as multiple spindles and turrets have been developed by leading machine tool builders. The efficiency of complex machine tools is largely dependent on how the machining components are utilized. The main thrust of this paper is twofold: (1) Proposition of a nonlinear process planning based on the STEP-NC (STEP-compliant data interface for numerical controls) paradigm whose data model is formalized as ISO 14649, and (2) Development of an optimal solution algorithm for process planning for complex machining. The developed algorithm is based on the branch-and-bound approach and heuristics derived from engineering insights. The developed process planning method and optimization algorithm were implemented and tested via the TurnSTEP system developed by our research team. Through the experiments, we are convinced that the new process planning and algorithm can be used as a fundamental means for implementing the third type of STEP-NC [Suh S. TurnSTEP: Tools to create CNC turning programs. In: White paper presented on STEP Implementers' Forum ISO TC184/SC4 Meeting. 2004], i.e., an Intelligent and Autonomous STEP-NC system for the CAD-CAM-CNC chain supporting e-Manufacturing.

Keywords: ISO 14649; STEP-NC; CAPP; Nonlinear process planning; Complex machining

1. Introduction

With the advancement of machine tool building and computer numerical control (CNC) technology, various configurations of CNC machine tools have been undergoing continuous development. In the typical machine tool scenario, machine tools with as many as 20 mechanical axes with 10 simultaneous controls are commonly seen. Using highly sophisticated machine tools, manufacturing productivity can be greatly enhanced because the entire machining operation required to fabricate the part can be made in a single setup in the same machine tool. For instance, the whole part can be machined without off-loading by using dual spindles, while the machining time can be greatly reduced and by using multiple turrets. Moreover, both turning and milling operations can be done in the same machine tool.

Specifically, *complex machining* is defined as a set of machining operations that can be typically made by multi-channel complex machine tool (MCCM), equipped with more than one spindle and turrets for both turning and milling operations. MCCM has been developed by the machine tool makers in response to industrial demands for complete machining of complex parts with single machine tools. For example, in an MCCM equipped with 2 spindles and 2 turrets, the upper turret has four degrees-of-freedom of motion: three (X, Y, Z) for translation and one (B) for rotation. Together with the C-axis motion from the spindle, the machine can perform 5-axis milling operations. The lower turret can be used for turning of the parts attached to the two spindles. Further, this type of machine tool is normally equipped with part loading and unloading mechanisms.

Compared with conventional machine tools such as turning machines, for instance, a number of advantages can be

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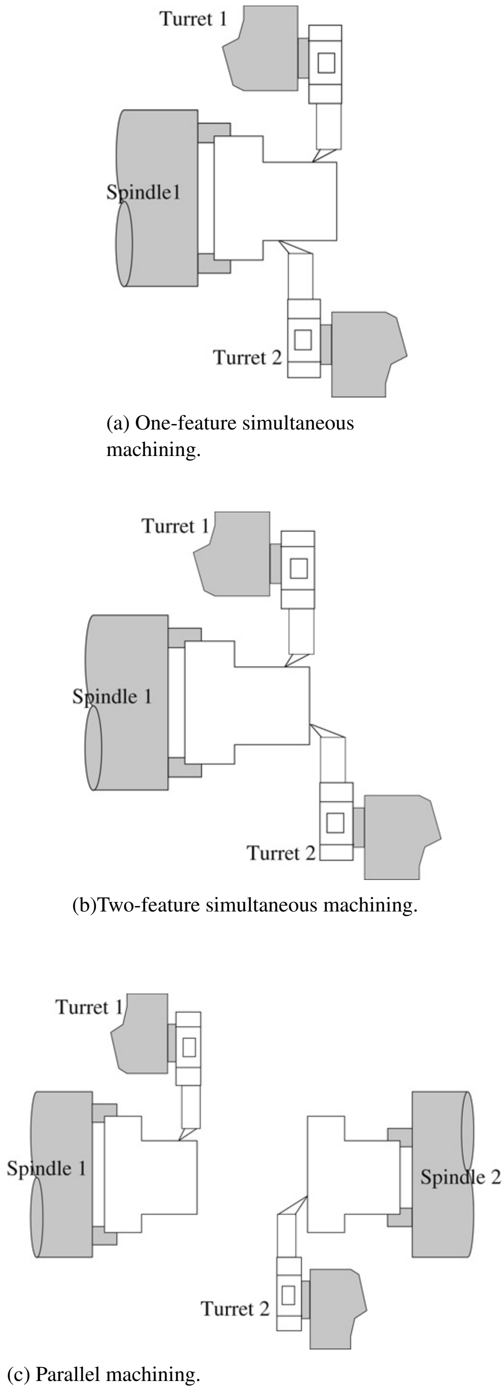

Fig. 1. Three feasible machining modes in MCCM.

obtained. (1) Complete machining: In one setup of the workpiece, all operations required for the workpiece can be made by MCCM. (2) Automated setup operations: The whole operations from loading of the workpiece to unloading after complete machining can be automated. (3) One-feature simultaneous machining (OFSM): The workpiece can be machined by more than one cutting tool to reduce the cycle time, i.e., the same removal volume (formalized as *turning_machining_feature* in ISO 14649-12 [1]), is machined by more than one cutting tool, as shown in Fig. 1(a). (4) Two-feature simultaneous machining (TFSM): The cutting tools remove different *turning_machining_features* [1], as shown in Fig. 1(b), to reduce the cycle time. (5) Parallel machining (PM): Distinguished from the two simultaneous machining cases, two workpieces attached to the two spindles may be machined by more than two turrets, as shown in Fig. 1(c).

MCCM's great potential is not fully realized in practice, mainly due to inefficient process planning methods for complex machining with MCCM. Process planning herein means micro-process planning (dealt with in ISO 14649) involving a single type of machine tool, not macro-process planning (dealt with in ISO 10303 AP240) involving more than one machining process with more than one machine tool, e.g., Kruth [2]. In most industrial practices, process planning and part programming are done manually by skilled operators, or by computer-aided systems installed either in off-line CAM systems or in on-line CNC controllers, the so-called CAPS (Conversational Automatic Programming System). Moreover, with CAPS, the current degree of automation and optimization achievable is not sufficient. Commercial CAM systems do not offer nonlinear process planning or algorithms for synchronous machining, but do provide a suitable environment for users to select a synchronous machining mode for each turret and specify cutting tools, removal volumes, and process attributes.

In the literature on CAPP, Elmaraghy [3] summarized relevant research including future prospects. Specific problems of process planning for MCCM have not been dealt with much in the previously reported open literature. The previous literature related with micro-process planning of turning and complex machining operations can be summarized as follows. For turning operations, Zang [4] proposed a knowledge-based, feature recognition method called EXCAP, and Joseph [5] and Kalta [6,7] expanded the functionality of EXCAP system by adding CAM and CAD functions. Barakat [8] developed a variant CAPP system, where a process plan is generated by modifying a process plan for a similar part. The above CAPP systems are subject to conventional turning machines and have a limitation in not supporting complex machining.

A group of researchers including Levin [9,10], Yip-Hoi [11,12] suggested algorithms for finding the delta volumes to be removed by turning for turn-mill parts and for generating the schedule for parallel machining. In their work, complex machining is limited to parallel machining. Note that complex machining is not necessarily the same as parallel machining where only one turret and only one spindle are utilized for complete machining, and hence their algorithms cannot be applied to the complex machining problems including simultaneous machining addressed in this paper. For complex machining, only a few works have been carried out. Chiu [13] proposed a genetic algorithm for scheduling a machining sequence. Veeramani [14] suggested a hybrid CAPP system, where the process plan is generated by means of computer algorithm and user interaction.

As far as the paradigm of process planning is concerned, all previous research assumed that their (optimal) solutions found off-line are given to a CNC controller via machine tools and control-specific code, according to G-code (ISO 6983). Due