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An integrated approach for joint process planning and machine tool dynamic behavioral assessment

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Abstract

The current work introduces a novel approach for enhanced process planning where the machine tool kinematic and dynamic behavior is introduced and modeled. The proposed approach is structured in three main steps starting from the workpiece analysis, the dynamic cutting simulation till the fixturing system selection and the setup planning. The methodology introduced in the paper has been validated with reference to an industrial case study and results have been described.

Keywords: Process Planning, Machine Tool Kinematics and Dynamics, STEP-NC, MWS execution simulation

1. Introduction

Process planning for mechanical component cutting has been a widely discussed topic in literature. During last 20 years, various approaches for computer aided process planning (CAPP) have been developed [1, 2]. Two interesting STEP-NC based [3] approaches were proposed by Chung and Suh [4] and Nassehi et al. [5] for the generation of optimal process plans respectively for turning and prismatic parts. Recently, Yusof et al. [6] provided a STEP-compliant CAD/CAPP/CAM system for asymmetric turn/mill parts based on a detailed description of a new system framework. New key factors such as process energy and process time have been introduced into process planning approaches by Sheng et al. [7]. Their idea was extended by Srinivasan and Sheng [8] that proposed a process planning analysing at the micro level the cutting tool parameters and at the macro level setup planning.

However, most of the approaches in the literature do not aim at taking into account machine tool kinematic or dynamic characteristics. The idea behind the current work is to give a second dimension to the process planning by proposing an integrated process planning and machine tool development approach. The integrated process planning and machine tool development approach would lead to the following novelties:

- given the Machining Workingsteps (MWS) technological parameters, the approach supports the identification of the shop-floor machine tools capable of exploiting the process;
- determining the MWS technological parameters in order to optimize the MWS execution on each machine tool.

The proposed approach takes into account both tradition machining centers and a new generation of machine tools, called *Dematerialized machine tool*, embracing design principles such as the reduction of material amount and energy usage as well as the focalization of machine performance on specific operation requirements [9,10].

The paper is structured as follows: Section 2 introduces the proposed enhanced process planning approach; Section 3 outlines the dynamic modeling of machine tools; Section 4 describes the benefits of the approach with reference to a case study and discusses the industrial benefits; Section 5 summarizes the main conclusions and introduces the future developments.

2. Proposed approach

The process planning approach proposed in the current work is structured in three major phases, as illustrated in Fig. 1. The first phase is the workpiece analysis whose main purpose is to determine the set of operations required to obtain the finished part together with the operations representation in the STEP-NC standard [3]. Alternative machining strategies, i.e. alternative operations, could be considered for processing parts and finally process parameters are determined and passed to the next phase.

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The set of operations - modelled as MWS - is then utilised in the second phase of the approach that is responsible for the dynamic cutting simulation of each operation by referring to the machine tools available in the shop floor as well as the catalogue machine of a machine tool builder. This phase assesses the process feasibility of MWS on the machine tools by validating the choices about process parameters determined in phase 1 while relying on several MWS KPIs. Examples of relevant KPIs for deciding MWS feasibility and quality are surface roughness, maximal spindle power and torque. Moreover, on the basis of surface roughness, production time, energy consumption and tool wear, a trade-off among process/product quality, production time and production cost is considered. The third step concerns the selection of one or more fixture and the definition of workpiece orientation as well as the association of the operations to a given orientation (workpiece setup) [11-12]. The outcome of this phase, based on [9], is a process plan for the part that evaluates the machine tool kinematic structure. This is done in the last phase of the approach where the MWS feasibility is analyzed and the workpiece quality, production time and costs are investigated based on the MWS KPIs. The current work will give a specific focus on the evaluation of the relationship between the MWS and the machine tool dynamic behaviour rather than the setup problem.

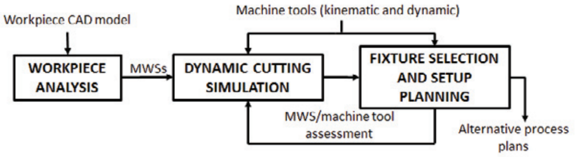

Fig. 1: Process planning schema

2.1. Workpiece Analysis

The workpiece analysis is the first activity in feature-based process planning [13]. It aims at defining the operations that are necessary for the complete machining of the workpiece. According to the STEP-NC standard, the geometric description of the region to be machined (machining features) and the strategy of machining (machining operations) have to be defined. The association between a feature and an operation is called machining workingstep (MWS). In case a feature requires roughing and finishing operations to be machined, more machining operations will be associated to the feature. Moreover, since a region can be machined on the basis of alternative strategies in terms of cutting tools, machining parameters or tool path, it results that alternative operations can be defined for the same feature. As a result, the final analysis could present alternative MWSs. The analysis takes into account 2.5D machining feature such as planar face, pocket, slot, step and round hole. Each feature is associated to a number of data related to the actual manufacturing execution such as the retract plane, cutting tool, technology (e.g. spindle speed, feed rate), machine function, tool path. The operation can be executed only if the machine tool accomplishes the requested technological capabilities. Conversely, the MWS parameters will be adjusted to respect the machine tool limitations.

Once defined the workpiece MWSs, the technological constraints between MWSs must be modelled [14]. In the present paper, two kinds of technological constraints are considered: precedence and tolerance constraints. Precedence constraints determine the technological sequence between operations (such as roughing before finishing operations). Tolerance constraints require the execution of more MWS in the same workpiece setup in order to ensure the tolerance specifications and related product quality. On the basis of technological constraints and alternative strategies, a network of the MWS is built. The MWS network is then passed to the second step of the proposed approach dealing with the dynamic cutting simulation.

2.2. Dynamic cutting simulation

In the metal cutting strategy, the objective of decreasing manufacturing time and costs is strictly connected to the necessity of ensuring the requested level of quality. The quality can concern directly the workpiece (WP) geometrical properties, or it may refer to the process, for instance, its efficiency in terms of energy consumption.

The WP quality is affected by all the phenomena that determine an undesired displacement of the tool with respect to the nominal path. A comprehensive assessment of WP quality entails an analysis of four major categories of phenomena: thermal deformations of machines and parts; volumetric positioning errors of the tool tip; dynamic interaction among machine, process and WP; trajectories errors due to CNC and/or feed drives performance (see Fig.). Due to the high demanding performance in terms of material removal rate (MRR) the modeling and minimization of vibrations either forced or caused by chatter instability (third category red framed in Fig. 2), represents a major limitation for improving productivity and part quality in metal removal processes. Vibrations occurrence has several negative effects: poor surface quality, out of tolerances, excessive noise, disproportionate tool wear, spindle damage, reduced MRR to preserve surface quality, waste of materials, waste of energy and, consequently, environmental impact in terms of materials and energy [15]. Besides the surface quality and the violation of tolerances, the other effects deal with process quality and have a direct impact of the overall production efficiency. The key for evaluating the level and the effects of vibrations onset is the so-called dynamic cutting process simulation, able to couple the forces originating from the material removal with the relative dynamic and static response between tool tip and workpiece [16]. While the simulation of single processes or machine characteristics is