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Review

Neural control strategy of constant cutting force system in end milling

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ABSTRACT

This paper discusses the application of neural adaptive control strategy to the problem of cutting force control in high speed end milling operations. The research is concerned with integrating adaptive control and a standard computer numerical controller (CNC) for optimizing a metal-cutting process. It is designed to adaptively maximize the feed rate subject to allowable cutting force on the tool, which is very beneficial for a time consuming complex shape machining. The purpose is to present a reliable, robust neural controller aimed at adaptively adjusting feed rate to prevent excessive tool wear, tool breakage and maintain a high chip removal rate. Numerous simulations and experiments are conducted to confirm the efficiency of this architecture.

Contents

1. Introduction

The use of computer numerical control (CNC) machining centers has expanded rapidly through the years. A great advantage of the CNC machining center is that it reduces the skill requirements of machine operators. However, a common drawback of CNC end milling is that its operating parameter such as spindle speed or feed rate is prescribed conservatively either by a part programmer or by a relatively static database in order to preserve the tool.

As a result, many CNC systems run under inefficient operating conditions. Even if the machining parameters are determined off-line by non-deterministic optimization algorithms based on artificial intelligence (neural networks and genetic algorithms) [1,2], they cannot be adjusted additionally during the machining process.

For this reason, CNC machine tool control systems, which provide on-line adjustment of the operating parameters, are being studied with interest. These systems can be classified into three types: a geometric adaptive compensation (GAC) system, an adaptive control optimization (ACO) system and an adaptive control constraints (ACC) system.

GAC systems enhance part precision by applying real time geometric error compensation for imprecision caused by varying machine temperature, imprecise machine geometry, tool wear and other factors [3].

However, due to the difficulty in on-line measurement of tool wear and machine tool temperature, there are no commercial GAC systems available [3].

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ACO and ACC systems enhance productivity by applying an adaptive control technique to vary the machining variables in real time [4]. ACO systems set up the most effective cutting condition for the present cutting environment. For this purpose, ACO systems require on-line measurement of tool wear. Due to this reason, few, if any, ACO systems are used in practice [3,5].

ACC systems increase productivity by maximizing one or many machining variables within a prescribed range bounded by process and system constraints [6,7]. The most commonly used constraints in ACC systems are the cutting force, spindle current and cutting torque. The operating parameters are usually feed rate and spindle speed.

Unfortunately, adaptive control alone cannot effectively control cutting forces. There is no controller that can respond quickly enough to sudden changes in the cut geometry to eliminate large spikes in cutting forces. Therefore, we implement on-line adaptive control in conjunction with off-line optimization. The optimization is performed with algorithm developed by Zuperl and Cus [8], Zuperl et al. [9] and Cus and Balic [10]. A neuro-fuzzy model that uses the concept of "feature manufacturability" to identify and recognize the degree of "pretentiousness—difficulty of machining" is studied with interest [11].

In our AC system, the feed rate is adjusted on-line in order to maintain a constant cutting force in spite of variations in cutting conditions.

The paper is organised as follows. The following section briefly describes the overall cutting force control strategy. Section 3 describes feed-forward neural control scheme. Section 4 covers the CNC milling simulator. Section 5 describes the experimental equipment of adaptive control system. Finally, Sections 6 and 7 present experimental results, conclusions and recommendations for future research.

2. System for off-line optimization and adaptive cutting force control

The overall force control strategy consists of optimizing the feed rates off-line, and then applying on-line adaptive control during the machining process. The basic idea of this design is to merge the off-line cutting condition optimization algorithm and adaptive force control (Fig. 1). Based on this new combined control system, very complicated processes can be controlled more easily and accurately compared to standard approaches. The objective of the developed combined control system is keeping the Metal Removal Rate (MRR) as high as possible and maintaining cutting force as close as possible to a given reference value. Combined control system is automatically adjusted to instant cutting conditions by adaptation of feed rate. When spindle loads are low, the system increases feeds above and beyond pre-programmed values, resulting in considerable reductions in machining time and production costs. When spindle loads are high the feed rates are lowered, safeguarding cutting tool from damage and breakage. When system detects extreme forces, it automatically stops the machine to protect the cutting tool.

The sequence of steps for on-line optimization of the milling process is presented below:

1. recommended cutting conditions are determined by ANfis (adaptive neuro-fuzzy inference system) models [12], which are basic elements of the software for selecting the recommended cutting conditions;
2. optimization of recommended cutting conditions by Particle Swarm Optimization (PSO) [9];
3. pre-programmed feed rates determined by off-line optimization algorithm are sent to CNC controller of the milling machine;
4. measured cutting forces are sent to neural control scheme;
5. neural control scheme adjusts the optimal feed rates and sends them back to the machine and
6. steps 4–6 are repeated until termination of machining.

The adaptive force controller adjusts the feed rate by assigning a Feed Rate Override percentage (FRO) to the CNC controller via Direct Numerical Control (DNC) on a 4-axis Heller, based on a measured peak force (see Fig. 1). The actual feed rate is the product of the Direct Numerical Control Feed Rate Override percentage (DNCFRO) and the programmed feed rate. DNCFRO is a controller variable associated with Override (%) currently selected via program DNC. If the software for optimization of cutting

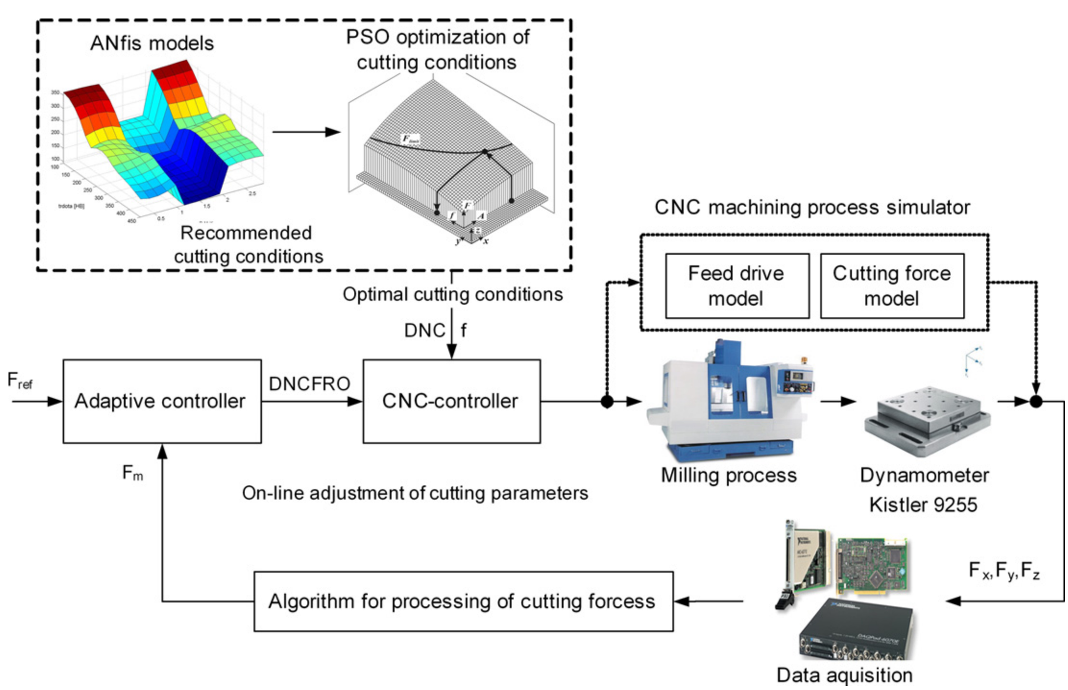

Fig. 1. Structure of combined system for off-line optimization and adaptive adjustment of cutting parameters.