CONTROL STRATEGY OF CONSTANT MILLING FORCE SYSTEM AND METAL REMOVAL RATE MAXIMIZION

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Abstract: An adaptive control system in conjunction with off-line optimization is built which controlling the cutting force and maintaining constant roughness of the surface being milled by digital adaptation of cutting parameters. In this way it compensates all disturbances during the cutting process: tool wear, non-homogeneity of the workpiece material, vibrations, chatter etc. The basic adaptive control design is based on the control scheme (UNKS) consisting of two neural identificators of the process dynamics and primary neural regulator.

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 feedrate 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. For this reason, CNC machine tool control systems, which provide on-line adjustment of the operating parameters, are being studied with interest (Balic, 2000). 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.

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 researchers (Zuperl, 2004) and (Cus, 2003). In our AC system, the feedrate is adjusted on-line in order to maintain a constant cutting force in spite of variations in cutting conditions.

2 NEURAL FORCE CONTROL STRATEGY

The overall force control strategy consists of optimizing the feedrates 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 (Figure 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 feedrate.. Sequence of steps for on-line optimization of the milling process is presented below:

1. The recommended cutting conditions are determined by ANfis software (Mursec, 2000) for selecting the recommended cutting conditions.
2. Optimization of recommended cutting conditions by PSO optimization.
3. The pre-programmed feedrates determined by off-line optimization algorithm are sent to CNC controller of the milling machine .
4. The measured cutting forces are sent to neural control scheme.

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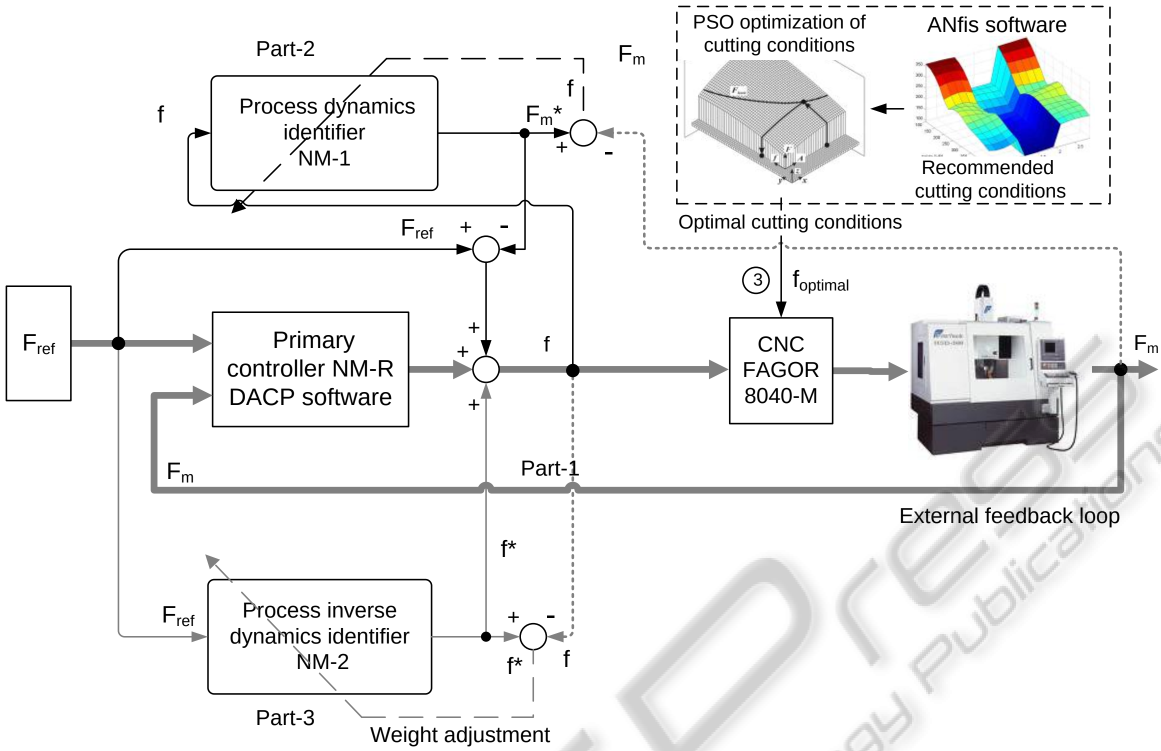


Figure 1: Adaptive force control combined with off-line optimization.

5. Neural control scheme adjusts the optimal feedrates and sends it back to the machine.
6. Steps 1 to 3 are repeated until termination of machining.

The adaptive controller adjusts the feedrate by assigning a feedrate override percentage to the CNC controller on a 4-axis Heller, based on a measured peak force. The actual feedrate is the product of the feedrate override percentage (DNCFRO) and the programmed feedrate. The fundamental control principle is based on the neural control scheme (UNKS) consisting of three parts (Figure 1). The first part is the loop known as external feedback (conventional control loop). The feedback control is based on the error between the measured (F_m) and desired (F_{ref}) cutting force. The primary feedback controller is a neural network (NM-R). The second part (NM-1) acts as the process dynamics (cutting dynamics) identifier. The third part of the system is neural network 2 (NM-2). The NM-2 learns the process inverse dynamics. The UNKS operates according to the following procedure. The sensory feedback is effective mainly in the learning stage. This loop provides a conventional feedback signal to control the process. During the learning stage, NM-2 learns the inverse dynamics. As learning proceeds, the internal feedback gradually takes over the role of the external feedback and primary controller. Then, as learning proceeds further, the inverse dynamics part will replace the external feedback control. The final result is that the plant is controlled mainly by NM-1 and NM-2 since the process output error is nearly zero.

3 EXPERIMENTAL SET-UP

The data acquisition equipment consists of dynamometer, fixture and software module. The cutting forces were measured with a piezoelectric dynamometer (Kistler 9255) mounted between the workpiece and the machining table. The interface hardware module consists of a connecting plan block, analogue signal conditioning modules and a 16 channel A/D interface board (PC-MIO-16E-4). In the A/D board, the analogue signal will be transformed into a digital signal so that the LabVIEW software is able to read and receive the data. The ball-end milling cutter with interchangeable cutting inserts of type R216-16B20-040 with two cutting edges, of 16 mm diameter and 10° helix angle was selected for machining.
The cutting insert material is P10-20 coated with TiC/TiN, designated GC 1025.

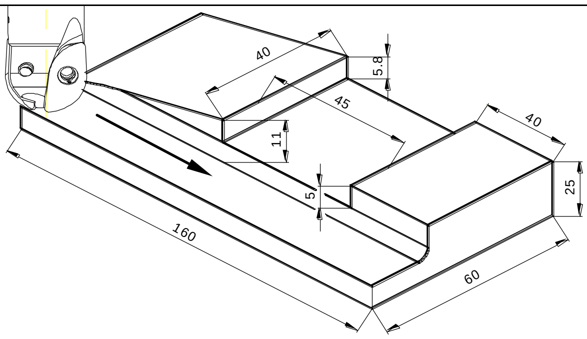
Experiment: Prismatic Workpiece 	
Test_A Constant feedrate	***Cutting conditions:*** Feedrate: 0.08mm/tooth, Cutting speed: v=80m/min, Pre-programmed axial depth of cut A_D=2 mm, Radial depth of cut R_D =4mm, F_{ref}=270N (Kopac, 2002), Result: Figure: 3a.
Test_B Proposed adaptive control system	Starting feedrate: 0.08mm/tooth, Allowable adjusting rate: 00.8 - 0.20 mm/ teeth, Cutting speed: v=80m/min; Result: Figure: 3b.

Figure 2: Plan of experiment; Cutting conditions for prismatic workpiece.

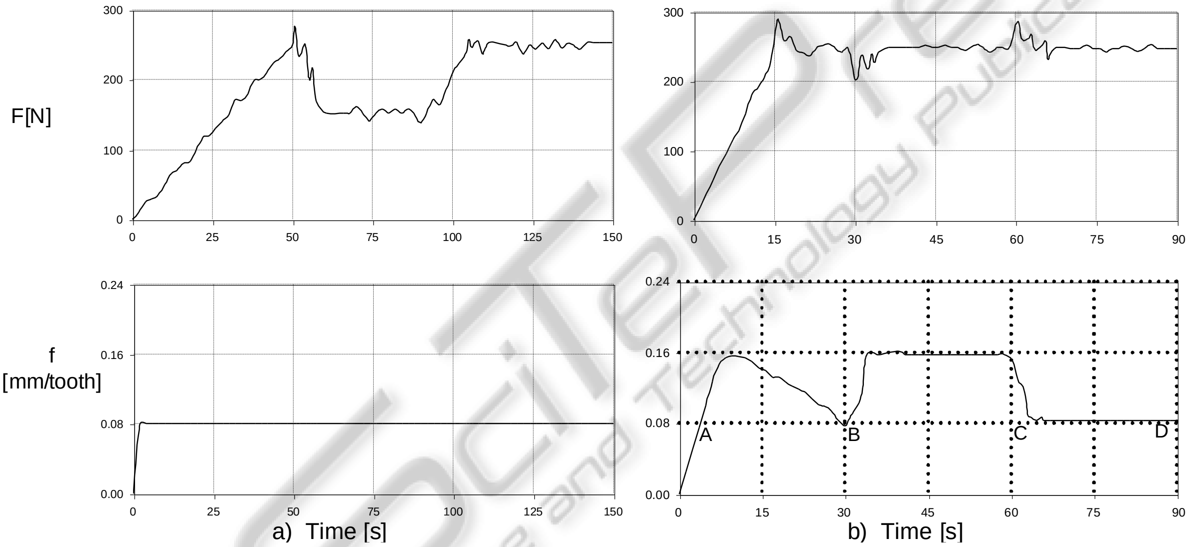


Figure 3: Response of MRR, resulting cutting force and feedrate. a) Conventional milling-Test_A. b) Milling with proposed adaptive control system-Test_B.

4 PROGRAM DACP

The program for digital adaptation of cutting parameters (DACP) is developed by software packet LabVIEW 7. During developing of DACP program the following requirements are taken into consideration:

- It must established communication between dynamometer and data acquisition card,
- Enable the selecting of measuring channels and calibration of measuring system,
- Establish communication with CNC controls,
- Actuate visual and sound signals in case of cutting tool overloading.

Control panel of DACP consists of three main parts. Upper part of panel is a monitoring part. Monitoring part has switches which enable user to define scanning parameters, measuring ranges, and accuracy of measuring.

Middle part is a control part. It consists of four buttons for controlling the milling process. Reference cutting force and desired surface roughness is set into the system by two graphical slides. All important information about communication state is displayed at the bottom of control panel. A communication module was developed to communicate with CNC via an RS-232 serial line.

5 EXPERIMENTAL TESTING OF CONTROL SYSTEM

The stability and robustness of the proposed control strategy is verified by experiments on a CNC milling machine for Ck 45 and 16MnCrSi5 XM steel prismatic workpieces with variation of axial cutting depth. Details of the experimental conditions and the dimensions of the workpiece are shown in Figure 2. Feedrates for each cut are first optimized off-line, and then machining runs are made with controller action. The first test is conventional cutting with the constant feedrate (Test_A). In the second test, the proposed control system was applied to demonstrate its performance (Test_B). The parameters for adaptive control are the same as for the experiments in the conventional milling (Zuperl, 2003).

Figure 3 is the response of the cutting force and the feedrate when the cutting depth is changed. It shows the experimental result where the feedrate is adjusted on-line to maintain the maximal cutting force at the desired value.

6 RESULTS AND DISCUSSION

As compared to most of the existing end milling control systems (Chen, 2006), the proposed adaptive system has the following advantages: 1. the computational complexity of UNKS does not increase much with the complexity of process; 2. the learning ability of UNKS is more powerful than that of conventional adaptive controller; 3. UNKS has a generalisation capability; 4. insensitive to changes in workpiece geometry, cutter geometry, and workpiece material; 5. cost-efficient and easy to implement; and 6. mathematically modeling-free.

Comparing the Figure 3a to Figure 3b, the cutting force for the neural control milling system is maintained at about 250N, and the feedrate of the adaptive milling system is close to that of the conventional milling from point C to point D. From point A to point C the feedrate of the adaptive milling system is higher than for the classical CNC system, so the milling efficiency of the adaptive milling is improved.

The time analysis for conventional and adaptive control system has been curried out. By adaptive control system of time saving of 40% with one cut was reached. The complete machining requires 15 cuts; thus machining of a simple workpiece is shortened for 155 seconds.

The system remains stable in all experiments, with little degradation in performance. The results reached are in accordance with the objectives of researches, according to which the controlled cutting force must not deviate from the desired value for more than 10% (Zuperl, 2005).

7 CONCLUSIONS

In this paper, an inteligent control algorithm that controls feedrate is proposed to regulate the cutting force. On the basis of the cutting process modeling, off-line optimization and neural control scheme (UNKS) the combined system for off-line optimization and adaptive adjustment of cutting parameters is built. This is an adaptive control system controlling the cutting force and maintaining constant roughness of the surface being milled by digital adaptation of cutting parameters.

In order to check the applicability of the adaptive control algorithm, cutting experiments were carried out under various cutting conditions, different tool diameters and different work materials. Experiments have confirmed efficiency of the adaptive control system, which is reflected in improved surface quality and decreased tool wear.

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