VARIABLE GAIN ADAPTIVE CONTROL SYSTEMS FOR MACHINE TOOLS

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PROGRAM OBJECTIVES: Computer Numerically Controlled (CNC) machine tools are gaining widespread acceptance in industry. With CNC machine tools the specification of the operating parameters (i.e., feeds and speeds) is left to the experience and judgement of the part programmer, who tends to select conservative values. Unfortunately, this results in a reduction of the production rate. Adaptive control (AC) systems are aimed at providing an additional level of control to automatically adjust the operating parameters on-line, so as to maximize the metal removal rate (MRR). AC systems, however, are not widely used in practice due to the following factors:

1. A lack of detailed understanding of the machining process.
2. Reliability problems with sensors and other hardware associated with AC systems.
3. Machining time may comprise as little as 5% of the total production time, thus, increases in MRR may not have a significant impact on production rates without significant improvement in tool changing, parts handling, etc.
4. Performance and stability problems associated with AC systems due to the variable nature of the machining process.

The objective of our program is to address the last problem through the development of high performance, stable AC systems. Specifically our goals are:

1. To design a variable-gain or parameter adaptive AC system which will adapt the AC controller to the changing process

where $y(k)$ is the average cutting force at time $t = k\Delta t$, Δt is the sampling period, $u(k)$ is the feedrate command (pulses/sec) to the stepping motor at time $t = k\Delta t$, and a_1 and b_0 are process parameters which depend on cutting conditions (e.g., spindle speed, depth-of-cut, material properties, etc.) and the sampling period Δt. In the simulation results presented below, we assume that $a_1 = -0.1$ and is constant, whereas $b_0(k)$ changes with time due to step increases in the depth of cut. The depth of cut changes from 1mm to 2mm at $t = 3.33$ and to 3mm at $t = 6.67$ seconds.

Figure 2 shows the behavior of the above process with the integral control law,

$$u(k) = u(k-1) + k_i(u^m - y(k)) \qquad (2)$$

where u^m is the desired reference force and k_i is the integral control gain. The gain k_i is selected using standard pole assignment techniques. The simulation results in Figure 2 clearly show that the system becomes unstable with integral control at large depths-of-cut.

The model reference adaptive controller (MRAC) uses the reference model,

$$y^m(k+1) = 0.5y^m(k) + 0.5u^m \qquad (3)$$

and generates the control input as follows [3],

$$u(k) = [y^m(k+1) - 0.5y^m(k) - \hat{r}_0(k)y(k)]/\hat{b}_0(k) \qquad (4)$$

where $\hat{r}_0(k)$ and $\hat{b}_0(k)$ are adjusted according to adaptation rules given in [3], during the milling operation. The simulation result in Figure 3 shows that the MRAC controller is able to eliminate the instability problem observed for the integral controller in Figure 2.

These results together with previously reported results [4], show that both self-tuning [5] and model reference adaptive control [2] strategies are promising candidates for the design of adaptive controllers for machine tools. Progress toward the evaluation of these and other strategies on actual machining tests is described below.

EXPERIMENTAL STUDIES: Due to the move of the Department of Mechanical Engineering and Applied Mechanics from Central Campus to the North Campus of the University of Michigan, our experimental program is proceeding more slowly than expected. The move is now essentially complete and we look forward to working in improved facilities during the coming year.

While much of our theoretical work involves numerical simulation studies it is also necessary to test control algorithms on physical systems. This could be done by running actual machining tests, but there are two problems with this. First, extensive machining tests are expensive and time consuming. Second, should a controller become unstable a dangerous machine wreck could occur. To address these problems we have built and tested interfaces between our digital computer and an analog computer. This allows us to run a digital simulation, then if the controller looks promising it can be tested in a realistic environment with the problems that occur in the control of physical systems by controlling the analog model of the cutting process. This system provides all the features of controlling the physical system (i.e., sampling, noise, etc.) without the expense and difficulties of extensive machining tests. When a controller functions well on the analog computer and the implementation problems are worked out the controller can be evaluated on a limited number of actual machining tests.

We are currently making some repairs on our force dynamometer for the mill. Once these repairs are finished the milling set up will be fully operational.

When the milling set up is complete we will begin working on the interface testing for the lathe while the preliminary machining experiments are being conducted on the mill. Over the next year we will also continue improving our simulation facilities and continuing evaluation of various controllers.

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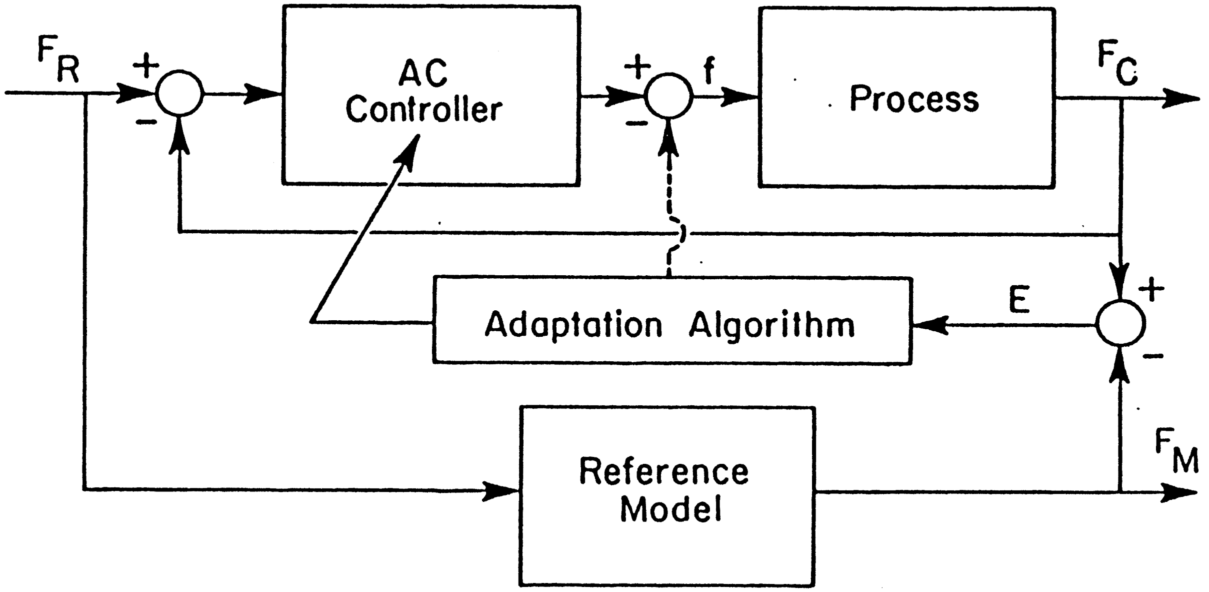

Figure 1. Structure of a Model Reference Adaptive Controller (MRAC)

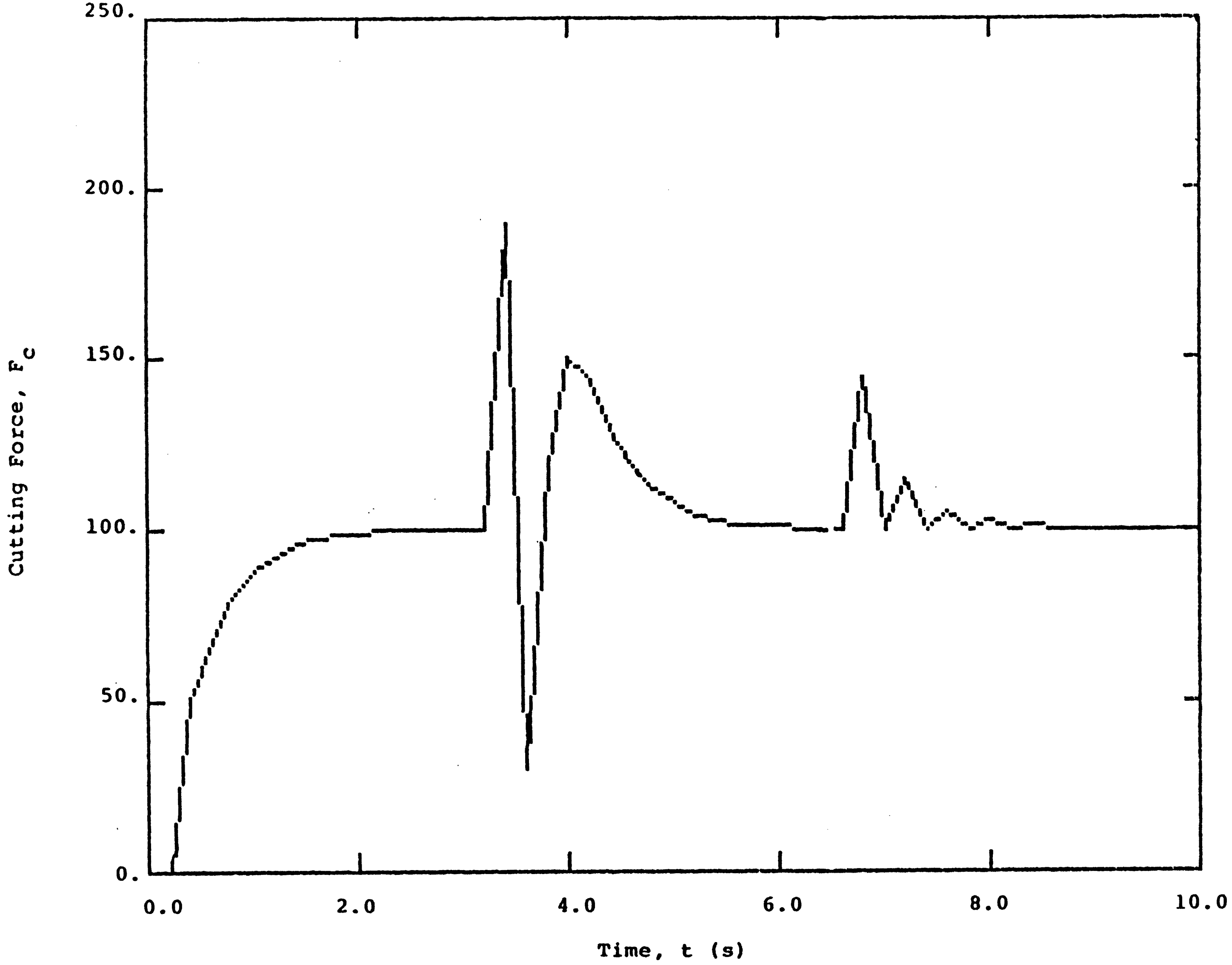

Figure 3. Simulation Results for Model Reference Adaptive Control (MRAC) of a Single-Axis Stepping Motor Driven Mill