A DIGITAL ROBUST CONTROLLER FOR CUTTING FORCE CONTROL IN THE END MILLING PROCESS

ABSTRACT

In this work a digital robust controller is designed via Quantitative Feedback Theory (QFT) to maintain a constant cutting force in the presence of parametric uncertainty for a time varying end milling process. The QFT controller is designed using the delta transform method for discrete systems. The controller is designed to limit the overshoot and settling time of the cutting force levels over a range of cutting parameters. Models are presented for the cutting process and machine dynamics including parametric uncertainty, and these models are used to develop a controller which meets given tracking and regulation specifications for all plant values. Good experimental results are obtained by implementing the controller on a high speed milling machine.

APPROACH

Quantitative Feedback Theory (QFT) was proposed as a method of designing robust controllers for plants with parametric and unstructured uncertainty. The structure of a QFT controller is shown in Figure 1. The controller *G(s)* and prefilter *F(s)* are designed to meet frequency bound specifications determined from time-response bounds.

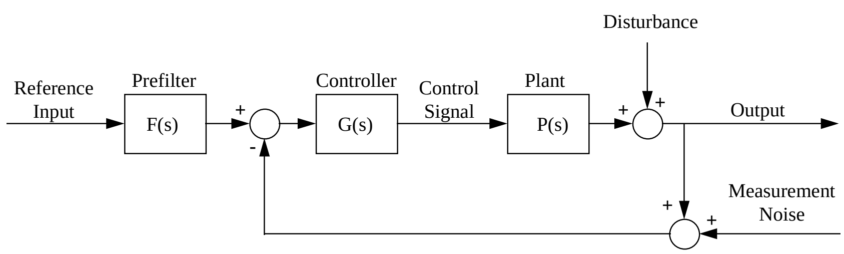

Figure 1 - Block Diagram of QFT Control System

While the QFT control scheme was designed for continuous systems, the need to control machine tools using a computer requires a discrete implementation. To this end, the delta transform is related to the forward shift operator *q* by

$$\delta = \frac{q-1}{T} \tag{1}$$

EXPERIMENTAL SETUP

The proposed controller was implemented using a high-speed horizontal milling machine. The controlled axis in the feed direction is driven by a 20 hp motor which gives the feed table a maximum speed of 300 ipm. The spindle is rated at 100 hp and is capable of 10,000 rpm. A 2-

inch diameter 4-flute end mill was used with a spindle speed of 1800 rpm. Figure 2 shows the experimental setup.

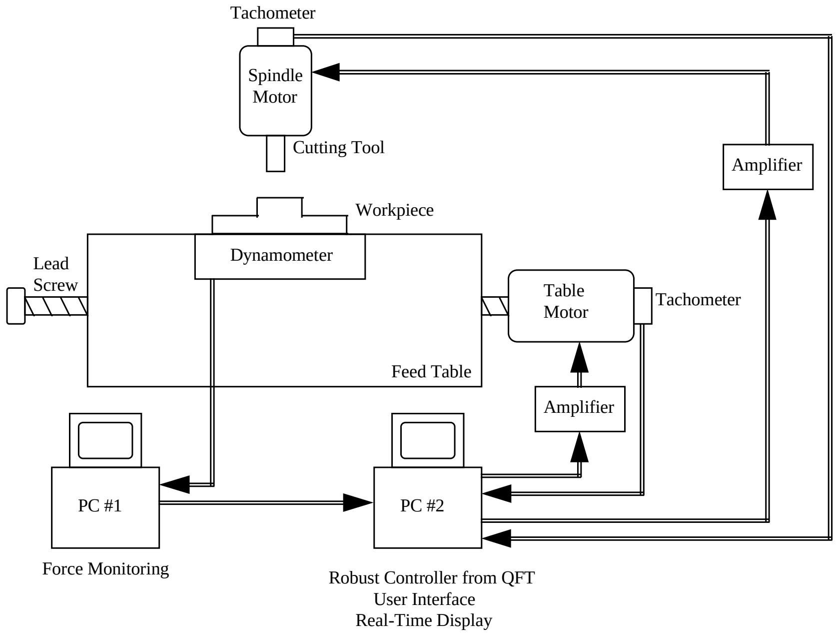

Figure 2 - Control Layout of the Experimental Setup

Two PC/486's were used in the setup. Each PC used a National Instruments AT-MIO-16 analog I/O board. LabWindows software was used to develop the control code for each machine. PC #1 monitored the cutting force and saved the peak force for each spindle rotation. This peak force was output to PC #2. PC #2 controlled the spindle rpm level, which was preset by the user and held at a constant level during testing. PC #2 also performed the digital control calculations, and the feed table velocity signal was directly sent to the motor via D/A converter. All user selected variables such as approach speed and desired force levels were input to PC #2 via a graphical interface.

EXPERIMENTAL RESULTS

The discrete robust controller was implemented on the high speed milling machine under a range of conditions. The reference force in all cases was set at 1500 N. To generate tests which cover the range of parametric uncertainty in the design, each test had a constant radial DOC, from 0.76 mm (0.030 inch) to 2.03 mm (0.080 inch), with the axial depth of cut initially at 10 mm, increasing to 20 mm, and ending at 10 mm. The results of these tests are given in Figure 3 and 4.

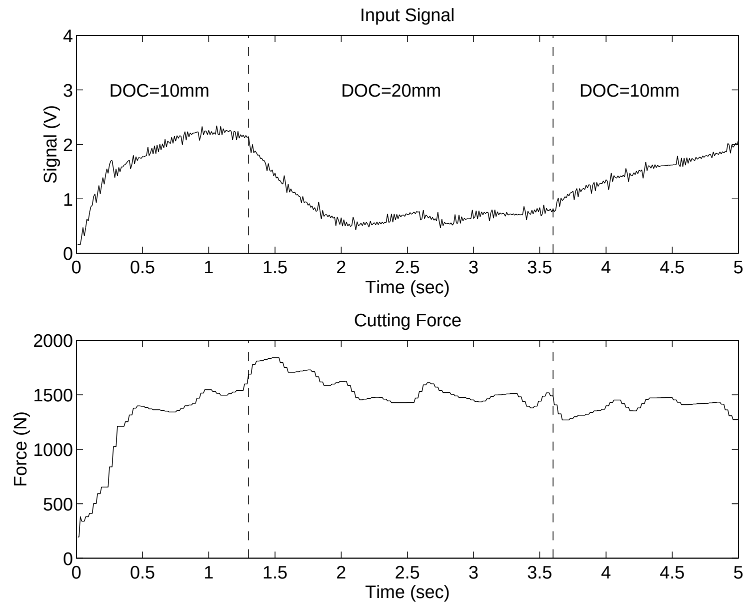

Figure 3 – Robust Control Results for Radial DOC of 0.76 mm (0.030 inch)
Reference Force of 1500 N, Axial DOC Noted on Graph

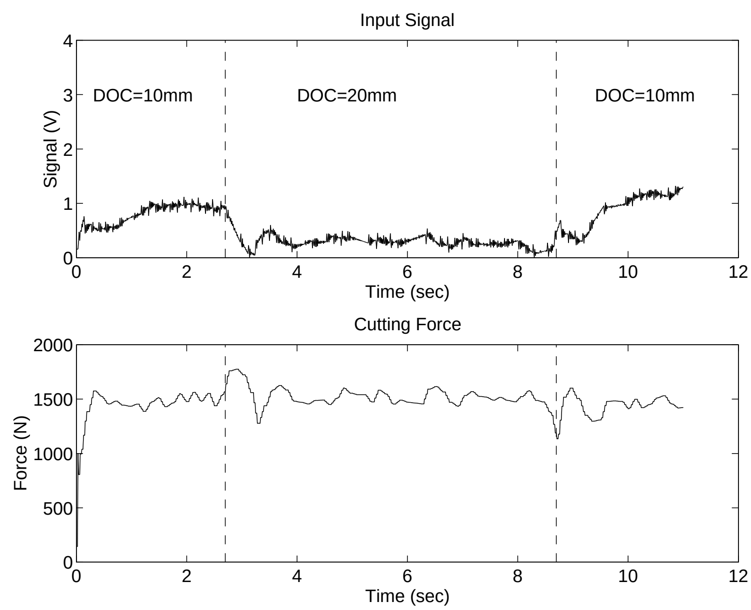

Figure 4 – Robust Control Results for Radial DOC of 2.03 mm (0.080 inch)
Reference Force of 1500 N, Axial DOC Noted on Graph