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CHARACTERIZATION OF METAL CUTTING DYNAMICS

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FINAL REPORT

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1. Introduction

1.1 Project Description

The necessity of designing efficient machine tools that produce parts of high quality and require minimum human intervention has motivated numerous research efforts towards the understanding of the fundamental aspects of metal cutting dynamics. Although several models of single point metal turning, the simplest of machining operations, are available, identification of all of the relevant processes, their interdependence and mathematical representation is a task of such difficulty that after five decades of intensive study a completely satisfactory predictive model does not yet exist. The majority of those models that have been derived from first principles are nonlinear. However, direct experimental evidence to support the postulated cutting theories is not available because of: i) Lack of fundamental measures of nonlinear dynamical behavior that may be applied to experimental data and used to gauge the predictive capacity of the cutting models. ii) Lack of signal processing techniques that appeal directly to the nonlinear nature of the cutting process.

A more crucial problem in metal cutting dynamics concerns the large amplitude, self-excited oscillations that develop under high metal removal rates. These have detrimental effects on both surface finish and dimensional accuracy of the workpiece, promote tool wear, lead to tool fracture and may damage the machine tool itself.

To address these fundamental problems the current research effort has i) enlarged the database of carefully controlled measurements of tool motions for critical ranges of the cutting parameters, ii) determined important characteristics and relationships between spectral and polyspectral indices, iii) defined the R-ratio and related functions of the singular values of the cumulant matrix which are capable of identifying the cutting state, iv) defined a function of the

1.2 Abstract

A Hardinge CNC lathe has been fitted with sensors and a data acquisition system for the measurement, processing and storage of accelerations and forces associated with orthogonal cutting. This system has been completely validated.

Orthogonal cutting experiments were designed in order to study the effects of critical cutting parameters on machining dynamics. Three major experimental sets were conducted. In the first set the depth of cut was increased in a stepwise fashion, while the workpiece surface speed, the spindle speed, and the tool feedrate were maintained invariant. In the second and third sets, the spindle speed and feedrate were varied, respectively, while maintaining all the other parameters invariant. In total over two hundred orthogonal cutting experiments were performed. In each experiment, the two non-zero components of the tool acceleration and the two non-zero components of the cutting force were measured. The experimental record of each signal contained from 180,000 and 250,000 data pointed sampled at 4096 Hz

Despite high noise levels, mutual information calculations with smoothing kernels and false nearest neighbor algorithms proved to be sufficiently robust to provide upper bounds on attractor dimension for all fifty data sets studied. These results prove that the infinite dimensional cutting process has an associated attractor of dimension ≤ 4 . This result is important as a guide to model construction.

An analysis of the power spectral sideband structure proved that sideband spacing is identical to the turning frequency. This result was further substantiated through envelope detection techniques. A linear delay model was shown to emulate the experimental power spectrum and possess predictive capacity.

The bicoherence index was computed for fifty time series. The existence of peaks in the

real time control are sought, computationally simple and efficient measures of amplitude were considered. Amongst these the ratio of the mean absolute deviation of details d3 and d4 was found to provide a consistent identification of pre-chatter and chatter states.

The following have been published under this contract [Berger and Rokni, 1993b], [Berger, Rokni, Minis, 1993c], [Rokni, Berger, Minis, 1995], [Berger, Minis, Chen, et al., 1995a], [Berger, Minis, Deng, et al., 1995b], [Berger, Minis, Deng, et al., 1995d], [Berger, Minis, et al., 1995e], [Berger, Minis, 1995f], [Berger, Minis, 1997], [Rokni, Berger, 1997]. The following have been or are about to be submitted for publication: [Minis, Berger, Chavali, et al., 1997], [Berger, Minis, Harley, et al., 1997]. See section 6, References, at the end of the report.