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QUALITATIVE AND QUANTITATIVE ANALYSIS OF STOCHASTIC PROCESSES BASED ON MEASURED DATA, II: APPLICATIONS TO EXPERIMENTAL DATA

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Analysis of stochastic processes governed by the Langevin equation is discussed. The analysis is based on a general method for non-parametric estimation of deterministic and random terms of the Langevin equation directly from given data. Separate estimation of the terms corresponds to the decomposition of process dynamics into deterministic and random components. Part I of the paper presented several possibilities for qualitative and quantitative analysis of process dynamics based on such decomposition. In Part II, some of these analysis possibilities are applied to experimental datasets from metal cutting and laser-beam welding.

1. INTRODUCTION

Most experimental data are to some extent noisy. Data can be noisy due to either the measurement procedure or the process generating the data. In the former case, the noise is superimposed on the measured data and uncorrelated to the process dynamics, while in the latter case the noise represents a constitutive part of the process dynamics, and the process is therefore stochastic. In Part I of this paper [1], analysis of stochastic processes with uncorrelated Gaussian noise was discussed. Such processes can be modelled by the Langevin equation, in which the temporal evolution of a process is determined by a sum of deterministic and random terms. The deterministic term usually describes the global dynamics of the process, whereas the random term describes some kind of environmental noise or noisy input which affects the process state but does not affect the process parameters. It was shown in Part I [1] as to how both the deterministic and random terms can be estimated from data and analyzed. The aim here is to apply these analysis methods to analyze experimental data from metal cutting and laser-beam welding. Metal cutting is an example in which the deterministic and random terms of the Langevin equation can be related quite reasonably to the actual physical phenomena involved in the process. For laser-beam welding, such relations are not easy to establish. However, the analysis methods presented in reference [1] can nevertheless be used to extract relevant information about the process dynamics from stochastic data.

2. ANALYSIS OF EXPERIMENTAL DATA

2.1. METAL CUTTING

The dynamics of metal cutting involve various non-linear phenomena such as material flow and fracture, friction between the tool and the workpiece, coupled vibrations of

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a machine–tool–workpiece structure, etc. When a cutting process is modelled on a macroscopic scale as a mechanical oscillatory system, the dynamics of the cut material can be treated as a source of random influence on a deterministic process. Assuming that these influences are uncorrelated and Gaussian, the dynamics of metal cutting can be modelled by the Langevin equation in which the deterministic and random terms describe the deterministic machine–tool–workpiece dynamics and the random influences of the cut material respectively.

In machining literature, two dynamically different cutting regimes are roughly distinguished: chatter-free cutting and cutting accompanied by chatter. Chatter denotes self-excited large-amplitude vibration of the machine–tool–workpiece structure. As an unfavorable cutting regime, chatter has been studied intensively. Analyses of non-linear models of a cutting process have revealed that the transition from chatter-free cutting to chatter corresponds to a sub-critical Hopf bifurcation from a stable fixed point to a stable limit cycle [2, 3]. These analytical results have been confirmed experimentally [4]. As shown in reference [5] and below, evidence in favor of such a description of chatter onset can also be obtained by time-series analysis using the methods discussed in reference [1].

As an example of a cutting process, turning on a lathe was chosen where a rotating workpiece is cut by a fixed tool. The experimental set-up is illustrated schematically in Figure 1. A dynamometer was used to measure fluctuations of the cutting force $\mathbf{F}$. The signals were sampled at a frequency of 100 kHz and each contained 220 000 data points. Details of the experiments can be found elsewhere [5].

Chatter-free and chatter-cutting regimes were achieved by varying the cutting depth a while keeping the rest of the cutting parameters constant. Portions of the cutting force fluctuations recorded in the two cutting regimes are shown in Figure 2. In the chatter-free regime, the cutting force F_c fluctuated erratically with occasional bursts of high-frequency periodic oscillations (Figure 2(a)), whereas in the chatter regime pronounced periodic fluctuations of the cutting force were observed with a dominant frequency markedly lower than in the chatter-free regime (Figure 2(b)).

The deterministic and random components of cutting dynamics, $\mathbf{h}$ and $\mathbf{G}$, were estimated in a two-dimensional phase space reconstructed from the recorded time series of the cutting component F_c of $\mathbf{F}$ using the delay co-ordinates, $\mathbf{x}(t) = (F_c(t-\tau), F_c(t))$. The delay τ was chosen as the time where the autocorrelation function decays to $1/e$, as suggested in

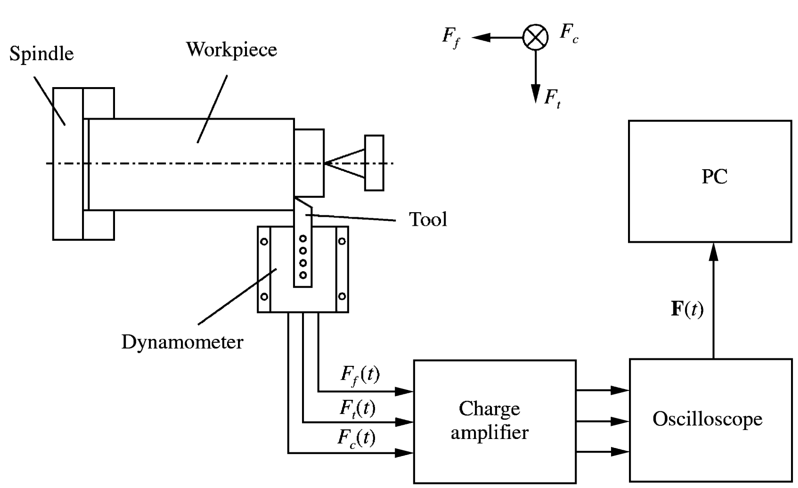

Figure 1. Experimental set-up for turning.