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BAYESIAN UPDATING OF DISCRETE-TIME DOMAIN MODEL OF CHATTER IN MILLING

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ABSTRACT

The regenerative effect, a delayed feedback loop inherent in milling dynamics, often leads to unstable vibrations and chatter, undermining machining quality and tool life. Therefore, accurately determining the modal parameters of tooltip vibrations or the machine tool's Frequency Response Function (FRF) at the tooltip becomes essential for achieving chatter-free machining conditions. Typically, the machine tool's FRF is obtained through modal testing techniques, such as impulse hammer tests, conducted when the machine tool is in an idle state. However, this approach is limited because machine tool dynamics change considerably under operational machining conditions due to factors such as spindle rotation, and process damping, rendering idle-state FRF measurements less reliable. To address this limitation, Operational Modal Analysis (OMA) provides a practical solution for identifying dynamic parameters under operational conditions by analyzing vibration signals recorded during milling. Nevertheless, OMA faces challenges, including harmonic excitation and inherent feedback loops, which complicate parameter identification. In response to these challenges, this study employs Bayesian inference, a probabilistic framework that integrates prior information with observed data to improve accuracy.

Furthermore, the Semi-Discretization Method (SDM), a discrete-time domain model, is used to relate tooltip modal parameters to the closed-loop system poles estimated through OMA. This method is subsequently used to build a surrogate model and generate the chatter limits. Bayesian inference is applied to estimate the posterior probability distributions of the modal parameters by combining prior distributions with information obtained from OMA observations. To reduce the computational, a surrogate model maps input modal parameters to output closed-loop system poles using SDM, and a sampling technique is used to generate samples from the posterior distribution of the model parameters according to the assumed priors and the likelihood function. To generate samples from the posterior, this study adopts Improved Transitional Markov Chain Monte Carlo (iTMCMC). Compared to conventional MCMC, iTMCMC offers faster convergence and better sample mixing by employing adaptive proposal distributions and importance resampling. This reduces computational overhead and proves to be a robust choice for accurate posterior estimation in Bayesian inference applications.

Finally, the probability distributions of the parameters are integrated into the chatter model to establish probabilistic chatter limits. Compared to existing data-driven methods for calibrating chatter model parameters, which require experimental observations under both stable and unstable conditions, the proposed approach requires only vibration measurements during stable conditions. Moreover, each new observation updates the chatter limit globally, enhancing practicality for industrial applications.