Chatter Vibration Control for Stability Improvement in Deep Internal Turning

Abstract

Chatter is a self-excited vibration phenomenon, which is caused due to mutual interaction between the dynamics of slender cutting tool and cutting process dynamics. It is the most important type of dynamic instability in metal cutting operations. For long overhang boring bars with high Length to Diameter (L:D) ratios, the dynamic stiffness of cutting tool substantially reduces as well as the critical limiting depth of cut, and the cutting process becomes unstable for almost any cutting conditions. Hence, active damping methods must be utilized in order to improve the stability of slender boring bars. The active vibration control methods can drastically increase the damping ratio and stiffness of cutting tool, compared to passive vibration control methods.

This PhD dissertation deals with the problem of chatter vibration control in deep internal turning operation. A long overhang boring bar is designed and manufactured in CAD/CAM Laboratory of Ferdowsi University of Mashhad. The characteristics of chatter vibrations in deep internal turning process, are experimentally observed in terms of acceleration signals and machined surface texture, for L:D ratios 4-7. The stable cutting is absolutely impossible beyond L:D = 6 with the steel boring bar, owing to the fact that the slender cutting tool becomes susceptible to chatter vibrations.

An electrodynamic shaker is both utilized for identification of forward path dynamics (as external exciter) as well as active damping of chatter vibrations (as controllable actuator). It is installed on an especially designed moveable bed, which is connected to the carriage of lathe machine tool. The dynamic models for the actuator and boring bar are identified, using the fundamental concepts of system identification theory. It is observed that the actuator dynamics is linear in terms of excitation amplitude, while the boring bar shows non-linear behavior. Hence, a parameter-varying transfer function is proposed for describing the dynamics of forward path, i.e. actuator-boring bar assembly. The obtained dynamic model is then used for the purpose of model-based controller design.

The non-collocated SISO control system includes an accelerometer sensor which measures the boring bar vibrations in the radial direction adjacent to tool tip, and the electrodynamic shaker which exerts an active control force to the boring bar body in the radial direction away from tool tip. Three different control algorithms are designed, analyzed and implemented on the closed-loop control system, in order to suppress chatter vibrations in deep internal turning operation. The slender boring bar L:D is 8 and the radial acceleration at tool tip is used as the feedback signal for all controllers.

The control algorithms include an optimal PID controller as well as an adaptive PID controller. Both controllers have neglected the effect of proportional and derivative gains due to stability issues, and are Direct Velocity Feedback (DVF) controllers. The optimal PID controller is designed according to the theoretical transfer function of the closed-loop control system. The optimal controller gain is defined according to the disturbance rejection criterion. In addition, by considering the dynamic characteristics of actuator and boring bar, the adaptive PID controller dynamically adjusts the controller gain in accordance with the intensity of chatter vibrations. Moreover, a feedback version of adaptive inverse control methods, which is known as Filtered-x Normalized LMS algorithm with Internal Model Control, i.e. FxNLMS-IMC algorithm, is utilized as the third benchmark controller for chatter suppression in deep internal turning operation. This algorithm is originally developed for the active attenuation of acoustic noise. Both impact control tests and cutting tests are performed in order to experimentally verify the efficiency of proposed active damping control methods.

The experimental cutting tests are performed on Aluminum alloy 6063. According to obtained results, the magnitude of chatter vibrations is effectively suppressed around the dominant bending mode of boring bar. All controllers show similar performance with a significant vibration attenuation level of at least 60 dB up to 70 dB. As a direct consequence of chatter attenuation, the machined surface roughness is highly improved in various cutting conditions. Finally, the performance of FxNLMS-IMC controller for suppression of regenerative chatter vibrations, reduction of actuator cost and enhancement of surface roughness is proved to be relatively better than the PID controllers.

Keywords

Active Vibration Control, Chatter Suppression, Stability Improvement, Boring Bar, Deep Internal Turning, PID Controller, Adaptive FxNLMS Controller