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Active chatter control in orthogonal cutting

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1. Abstract

Turning-machining is an important manufacturing process, widely used in industry. The dynamic interaction between the tool and the workpiece may cause regenerative chatter, that is associated with poor surface finish, reduced product quality and low productivity. The demand for accuracy motivates development of active vibration control methods based on realistic dynamic models of the turning process. This study investigates the performance of a novel active robust control law for chatter attenuation that is based on an extended dynamical model of the chatter regenerative process. The extended model describes an external turning process, and includes the influence of the workpiece elasticity and the actuator finite bandwidth.

Keywords: Regenerative chatter, orthogonal cutting, active control, UDE control.

2. Introduction

Chatter is a common dynamic phenomenon in cutting processes, expressed as self-excited vibration caused by the interaction of the cutting tool and the work piece structure ([1]). Chatter has several negative effects, for example, poor surface quality, lower productivity, short life span of cutting tools, damage of machine components, disturbing or even harmful noise and waste of material and energy. For these reasons, chatter prevention is a topic of wide interest. The most dominant cause of chatter is the regenerative effect due to the waviness at the workpiece surface.

One approach to reduce the regenerative effect is by active control methods. In this study, an extended dynamical model of the orthogonal turning process, is used for control systems design. The extended model does not neglect the elasticity of the workpiece, and by that, depends on the exact cutting position (i.e., the tool location along the workpiece, see Fig. 1). In addition, the model is formulated with uncertainties, representing the uncertain part of the model coefficients and an external disturbance. This approach poses new challenges in the design of active chatter control.

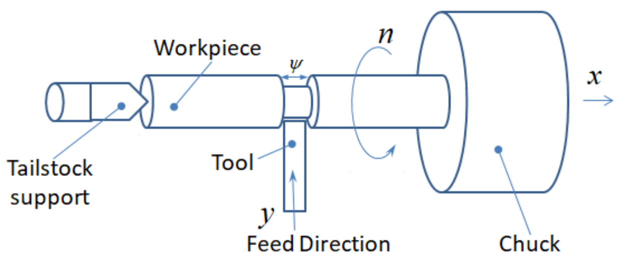

Figure 1: Orthogonal cutting

3. Dynamical model and control approach

Assume the workpiece motion can be represented by a single degree-of-freedom (SDOF) in the radial direction, then, the regenerative process is depicted in Fig. 2.

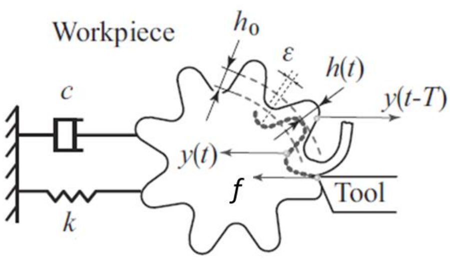

Figure 2: Single-degree-of-freedom orthogonal cutting model (photo from [2])

The equation of motion of the system (in Fig. 2) can be expressed as follows,

$$(m_0+\Delta m)\ddot{y}(t)+(c_0+\Delta c)\dot{y}(t)+(k_0+\Delta k)y(t)=f(t)+u(t)+\omega(t) \tag{1}$$

where $y(t)$ is the relative displacement between the tool and the workpiece (in a direction normal to the workpiece surface), $c=c_0+\Delta c$, $k=k_0+\Delta k$ and $m=m_0+\Delta m$ are respectively, the equivalent of damping, stiffness and mass of the workpiece, and c_0, k_0 and m_0 represent nominal values. The force $f(t)$ is the radial dynamic cutting force, $u(t)$ is the external control force and $\omega(t)$ is an unknown disturbance. The uncertainty is due the unknown cutting position along the workpiece. Since the workpiece elasticity is assumed meaningful, the location of the interaction between the tool and the workpiece has strong influence on model coefficients.

According to the regenerative chattering mechanism, the initial surface of the shaft is smooth without waves during the first revolution, but the tool starts leaving a wavy surface behind. It is caused by bending vibrations in the feed direction, which is also the direction of the radial cutting force. In the second revolution (see Fig.1), the surface has waves both inside (represented by $y(t)$) and outside (given by $y(t-T)$) of the cut nominal surface. The latter is due to vibrations during the previous revolution. Hence, the resulting chip thickness $h(t)$, is no longer a constant, but it varies as a function of the vibration frequency and the angular speed of the workpiece. Eventually, the cutting force $f(t)$ is proportional to the width of the cut ψ and the time varying chip thickness $h(t)$.

The extended dynamic model (1), represents an uncertain linear time-invariant (LTI) system with unknown external disturbances and a time delay. To deal with the suggested complex model, the Uncertainty and Disturbance Estimator (UDE) method ([3], [4]) is utilized for the controller design. The basic principle of this control method lays on a quick disturbance estimation and compensation mechanism. The UDE control algorithm takes advantage of the principle that a signal with a specific bandwidth can be approximated through its low pass filtering. Moreover, the method can be extended to uncertain linear and nonlinear systems with state delays. Nevertheless, the UDE method has never being implemented before for active chatter control in orthogonal cutting.

4. Contributions

The main contribution of this study stems from the investigation of the effectiveness of UDE to serve as a controller design platform for active chatter control in orthogonal cutting process. The study uses a detailed dynamical model, representing a small scale lathe (TOYO ML-360) test rig (in Fig. 3), being developed at our lab. Additionally, the finite bandwidth and the physical limitations of the intended (custom made) actuator (in Fig. 4) are all taken into account.

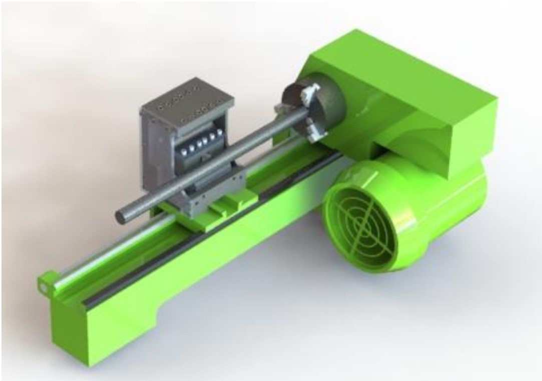

Figure 3: lathe (TOYO ML-360) test rig

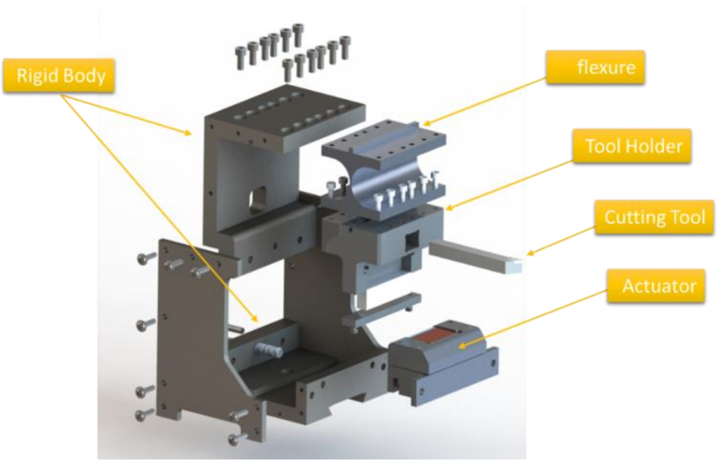

Figure 4: cutting tool custom (active) holder

5. Conclusions

In this research, a new control strategy for the problem of self-excited vibrations in orthogonal cutting machines was suggested. Extensive simulations based on a realistic dynamical model of the chatter process show that UDE based control laws can reduce chatter vibration significantly and improve machining throughput.

6. References

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