OVERVIEW OF EXPERIMENTAL INVESTIGATION OF CUTTING PROCESS Dynamic

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Abstract: This paper reviews experimental investigations and modeling of chatter vibrations in metal cutting. The dynamic modeling and chatter stability of turning, milling and drilling process is presented. Various stability models are compared against experimentally validated time domain simulation model results. Influence of chatter stability on surface roughness, chip thickness is presented. The influence of amplitude in amplitude frequency spectra of cutting force versus tool wear parameters is determined.

Key words: Dynamic, cutting, experimental

1. INTRODUCTION

Dynamics of metal cutting process have been a focus area of manufacturing research long time. Professor J. Tlusty contributed significantly to the understanding and engineering of dynamic cutting, stability and avoidance of chatter vibrations in machine tools. This article is compiled to review the current state of the knowledge in dynamic cutting, and in the research challenges in this area.

Tlusty presented the overview of dynamic cutting in the paper [1]. He focused extensively on the modelling and measurement of dynamic cutting coefficients, and their influence on the chatter stability in single point metal cutting processes.

With the advances in computer, sensor and high-speed machine tool technology, there have been new methods in predicting and avoiding chatter vibrations on the production floor.

Paper reviews the dynamics and research challenges in predicting both forced and self excited, chatter vibrations in machining operations.

Finite Element method based metal cutting process simulation models are most common in analysing the plastic deformation trends at the cutting edge, mechanistic models are mainly used in predicting cutting forces exciting machine tool vibrations [2, 3]. Tlusty [4] and Tobias [5] independently formulated the following absolute chatter stability law which has been widely used since 1950s:

$$a_{lim} = \frac{-1}{2K_r G(\omega)}$$  \hspace{1cm} (1)

The stability equation leads to positive real depth of cut only when the real part $G(\omega)$ of the transfer function between the tool and workpiece is negative. Eq. (1) gives only absolute depth of cut when the minimum value of $G(\omega)$ is considered as shown in Figure 1[5].

Fig. 1. Stability lobes based on orthogonal chatter theory.

2. STABILITY OF TURNING PROCESS

The general overview of a turning process is given in Figure 2 where the tool generates cutting action by moving in the feed direction towards the workpiece which rotates around its axis. The surfaces generated in stable and unstable cuts are also shown in Figure 2. It can easily be seen that chatter results in very poor surface quality.
model of dynamic milling, and included the structural dynamic models of both work piece and cutter at the cutting edge - finish surface contact zones [10, 11], see Figure 4. For example, a point on the cutting edge has coordinates, which are dependent on spindle speed, feed, tool geometry, radial immersion and depth of cut.

Details of the complete mathematical model of dynamic milling can be found in [11]. Once the oscillatory chip thickness is evaluated, the dynamic milling forces \( F_x(t), F_y(t) \) are predicted. The structural vibrations of the work piece and cutter are predicted by applying cutting forces to each structure at discrete time intervals:

\[
\begin{align*}
    m_x \ddot{x}(t) + c_x x(t) + k_x x(t) &= \sum_{j=1}^{N} F_{xj}(t) \\
    m_y \ddot{y}(t) + c_y \dot{y}(t) + k_y y(t) &= \sum_{j=1}^{N} F_{yj}(t)
\end{align*}
\]  

(2) 

3. MODELING OF DYNAMIC MILLING

The physical mechanism behind the stability lobe is illustrated in Figure 5, with the following example. If we consider a milling operation which chatters at frequency \( f_c \) [Hz], while cutting at a spindle speed of \( n \) [rev/min].

Altintas’s group developed the true kinematic
When the tooth passing and chatter frequencies match, exactly one vibration wave is left at each tooth period, which corresponds to the lobe number one (i.e., \( k=1 \)). Hence highest depth of cut is possible at this high speed. The peaks of the successive lobes correspond to integer divisions of chatter frequency, and produce integer numbers of full vibration waves at each tooth period. The lowest axial depth of cut corresponds to having worst regenerative phase shift (-180 degree) that leaves a half vibration wave at the end of each tooth period. Due to largest regeneration at this speed, where the inner and outer waves have opposite phase, the dynamic chip thickness grows and becomes largest during chatter.

4. DRILLING PROCESS

When drilling a full hole, a vibration of slightly less than 3 cycles per revolution is obtained, so this is a backward whirling motion. When cutting, rubbing and process damping forces at the chisel edge are removed from the model, thus simulating the drilling of a piloted hole, the least stable mode is found to be a little less than 7 cycles per revolution, which is also a backward whirl. Bayly’s results are illustrated in Figure 6, along with experimental measurement of one revolution for each case.

![Fig. 6. Simulated and experimental hole profile; (a),(b): full hole (3 sided); (c),(d): piloted hole (7 sided), after Bayly et al. [13]](image)

Figure 7 shows amplitude in amplitude frequency spectra of cutting force versus tool wear [14]. In the figure it is possible to notice width of flank wear land is influenced by dominating amplitudes until certain value of tool wear and id the area of catastrophic tool wear amplitudes are decreasing.

The test setup prepared for measuring acceleration of tool versus dimension of holder and direction of vibration of forces in direction of cutting speed and feed. The setup is prepared for measuring of turning process. It consists of accelerometer, amplifier, AD converter, notebook PC with user software applications. By use of computer software signal processing was provided.

![Fig. 7. Amplitude characteristic for the different values of the frequency and width of flank wear land](image)

![Fig. 8. Measuring set up with position of accelerometer](image)

Figure 9 shows graph of experimental signal with correlation curves [15].

![Fig. 9. Graph of experimental signal with correlation curves [15]](image)

5. CONCLUSION

High productivity and quality in machining strongly depend on the process dynamics and stability. Rigidity of machine tools and selection of process parameters are two main factors in dynamic behavior of cutting operations. In this paper, methods that can be used for analysis and modeling of machine tool structures and cutting process stability are reviewed. These methods can be used to analyze as well as improve the dynamic behavior of machining processes.

The significant progress has been made in modeling
machining processes. The frequency domain chatter stability laws in high speed milling have been well developed and used in industry effectively. Significant research efforts have been reported in time domain modeling of turning, boring and milling operations which allow the analysis of dynamic machining when the machine tool and workpiece stiffness, work material, tool geometry and cutting conditions are varied.

6. REFERENCES


Note:
This paper presents a part of researching at the CEEPUS III project, and Bilateral project between Serbia and Slovakia.