Commun Nonlinear Sci Numer Simulat 19 (2014) 4013–4023

Contents lists available at ScienceDirect

Commun Nonlinear Sci Numer Simulat

journal homepage: www.elsevier.com/locate/cnsns

New approach in dynamics of regenerative chatter research of turning ☆

Xilin Fu *, Shasha Zheng

School of Management Science and Engineering, Shandong Normal University, Jinan 250014, PR China

A R T I C L E I N F O

Article history:
Received 14 January 2014
Received in revised form 10 April 2014
Accepted 11 April 2014
Available online 26 April 2014

Keywords:
Chatter
Vibration
Turning
Discontinuous
Pulse

A B S T R A C T

In this paper, regenerative chatter phenomena in a turning process is discussed from impulsive dynamical point of view. By introducing the instantaneous pulse when vibration occurs and the vibratory condition set, we optimize the models and present a certain kind of second-order impulsive differential systems, which is a specific discontinuous dynamical system. Then we search for the general results of the nonoccurrence of chatter phenomena by discussing the number of the vibration pulse times, utilizing the method of flow theory in discontinuous systems and transversal property at the boundary. Our results give a convenient way to estimate the available parameters to keep the turning process stable.

1. Introduction

During a metal machining process, the cutting is often accompanied by a violent relative motion between tool and workpiece, which comes from the interaction between the metal cutting operation and machine tool, causing a instable dynamic phenomena called self-excited vibration. Further more, once the tool vibrates, the machine would cut into the wavy metal surface in the following cutting process and regenerate the undulations. Therefore, not only the instantaneous vibration of the system would affect the cutting process, but also the amount of undulation left from the previous cut would work, which causes a more complicate phenomena called chatter. Chatter was first identified as the most obscure and delicate of all problems facing the machinist by Taylor [1] as early as 1907. Actually, this undesired machine tool chatter is a vibrational instability of the metal-cutting process and present in almost all machining operation processes including turning, milling and drilling. Although it has been a popular topic for academic and industrial research for more than a century, it is still one of the main obstacles in achieving automation for most of the machine cutting processes [2]. As we know, excessive vibration between the tool and the workpiece would bring many adverse effects to the machining processes. Its catastrophic nature creates numerous problems to the total capacity usage of a machine toll in production, including unsteady process, poor surface quality, inefficient productivity rate, limited reliability and safety of the machining tool and so on.

Since that the chatter vibration causes so many inconveniences, many researchers try to find out the reasons why the chatter occurs, or the methods of improving the machine toll to avoid the chatter vibrations from various perspectives. In 1946, Arnold [3] firstly found that the most important characteristic property of chatter vibration is that it is not induced

☆ This work was supported by the National Natural Science Foundation of China (11171192) and the Specialized Research Fund for the Doctoral Program of Higher Education of China (20123704110001).

* Corresponding author.
E-mail address: xilinfu@gmail.com (X. Fu).

http://dx.doi.org/10.1016/j.cnsns.2014.04.003
1007-5704/

by external periodic forces, but rather that the forces which bring it into being and maintain it are generated in the dynamic cutting process itself. For the cause of chatter, many scholars have ever put forward some different theories, among which the generally-accepted ones are regeneration theory, vibration coupling theory, the negative friction theory and lag of cutting force theory. For the single degree of freedom systems, the above theories studied systematically the cause, the process, the occurring condition, and the energy change of the chatter, moreover, explained reasonably the chatter phenomena and the tenable conditions under respective theories. Considered that turning is one of the most widely used machining processes to produce a variety of products, we take the process of turning for example. From these over 50 years' research, we know that, in a turning process, three types of mechanical vibrations due to the lack of dynamic stiffness of the machine tool systems, as explained by Tobias [4], are free, forced and self-excited vibrations. Free vibrations are induced by shock and forced vibrations are due to unbalance effects in machine tool assemblies like gears, bearings, spindles. Free and forced vibrations can be easily identified and eliminated. Self-excited chatter vibrations are much more detrimental to finished surfaces and cutting tools due to their unstable behaviors which result in large relative displacements between the tool and workpiece [5]. However, self-excited chatter vibrations are still not fully understood due to its complex nature. They are most harmful for any machining processes including turning. Self-excited vibrations are also classified into primary chatter and secondary chatter [6]. Primary chatter is caused by friction between tool and workpiece, mechanical effects or mode coupling. Secondary chatter is caused by the regeneration of wavy surface on the workpiece. The latter one, which is always called regenerative vibration, is the most destructive among all the other vibrations.

In a word, chatter is caused by instability in the cutting process. Although there are many mechanisms of chatter instability as mentioned in [6], instability due to regeneration of surface waviness demonstrated by Tobias et al. [7] and Tlusty [8] is by far the most common cause of chatter. Also in [9], Merrit proposed regenerative chatter as a closed-loop interaction between the structural dynamics and the cutting process.

Fig. 1 is the illustration of regenerative chatter theory when the tool is turning a flexible surface, displaying the regeneration process in two turning operations. While machining, such vibration arises due to the interaction between the turning process and the machine tool structure, excites a relative motion between the machine tool and the workpiece, switches on the tool's turning over a previously machined undulated or wavy surface, and may finally lead to the chatter phenomena. And it would occurs at the frequency of the most dominant mode of the machine tool structure. According to this model, if all the chatter conditions are met, then the regenerative chatter occurs when the cut produced at time t leaves small waves in the material that are regenerated during subsequent passes of the cut. These conditions include the alternation cutting force caused by the disturbed system, enough energy supply to keep chattering which comes from the alternation cutting force, and so on. It is the result under the assumption that the workpiece is a rigid system. In other words, the active body of chatter can be only the turning tool systems. We can say that, chatter appears when out of phase or relative motion between the cutting tool and the workpiece is present. As a consequence, chip thickness changes and a wavy surface is generated; thus, the system will be excited on successive cutting passes giving rise to a regenerative effect as shown in Fig. 1.

From the very beginning, Tobias [10] and Meritt [9] had studied the modeling of the dynamic response, structural aspects and stability limit aspects of regenerative chatter. These studies are only applicable to orthogonal cutting, where the direction of the cutting force, system dynamics and chip thickness do not change with time. Nowadays, many scholars proposed various techniques to avoid this regenerative chatter vibration occurrence in the cutting process by either predicting its occurrence earlier or detecting it as soon as it occurs. Many engineers also tried active or passive control strategies to control chatter vibrations in order to obtain better surface finish of the product, higher productivity and tool life. Sexton [11] once investigated that the proper selection of the amplitude and frequency of the speed signal was dependent on the dynamics of the cutting process and constrained by the drive system response. Consequently, without systematic variation of the speed, this technique may even lead to chatter in an otherwise stable process [12]. Further more, Quintana and Ciurana [13] recently presented a state-of-the-art review of chatter in machining processes and classified current methods which ensure chatter-free (stable) cutting conditions. As indicated in Fig.1, the dynamic characteristics can be obtained through model testing by using the impulse method. Since that the process of chatter analysis, chatter stability prediction and chatter detection is highly complex which needs to be investigated independently for different cutting processes, while adjusting parameters in accordance with specific situations need tremendous work, the lack of the general theories in these processes provide motivation to many researchers to investigate such topic.

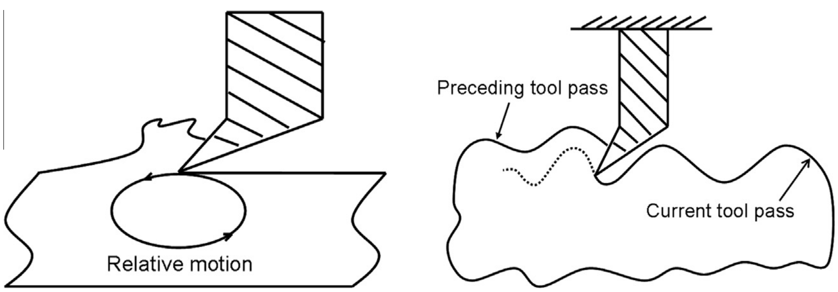

Fig. 1. Regeneration process in two turning operations.