Experimental Techniques for Chatter Avoidance

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The general trend towards lightweight components and stronger but difficult to machine materials leads to a higher probability of vibrations in machining systems. Amongst them, chatter vibrations are an old enemy for machinists with the most dramatic cases resulting in machine-tool failure, accelerated tool wear and tool breakage or part rejection due to unacceptable surface finish. To avoid vibrations, process designers tend to command conservative parameters limiting productivity. Among the different machining processes, turning is responsible of a great amount of the chip volume removed worldwide.

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1. Introduction

The study of chatter is closely related to the history of metal removal processes at the beginning of the 20th century. As early as 1907, Taylor, one of the fathers of modern machining, gives the first definition of chatter presenting this phenomenon as "perhaps the most obscure and difficult to ascertain" [1]. However, it was not until midcentury when its main causes were identified. Among the different types of vibrations, chatter vibrations are defined as self-excited vibrations. When the tool/workpiece contact is not stiff enough, an oscillation is generated between them causing a distortion in the chip thickness parameter between two successive periods, t and t-T, where t is be the actual time and T the workpiece rotation period in the context of turning. In this way, the process itself produces feedback causing a vibration whose frequency is near, but not exactly, to the natural frequency of the system. As a result, waves between subsequent passes lead to unacceptable surface roughness or even out of tolerance workpieces [2][3]. To avoid vibration problems, attention must be paid at the very early stage of process planning. Particularly, the authors identified the following items as possible sources of vibrations: (1) cutting tool (grain size, geometry, coating and wear and their effect on cutting forces) [4][5]; (2) workpiece material (type of material, homogeneity, hard grains, porosity, defects) [6][7]; (3) machine-tool (machine, spindle, toolholder, tool overhang, clamping) [8].

In a pioneering study, Arnold [9] characterizes in a very complete way the origin and onset of vibrations in the cutting tool when machining steel. In this study, the origin of chatter is found at the forces sustained by the cutting process itself and not external forces. Together with Arnold, pioneers in detecting and studying chatter mechanisms were Tobias, Fishwick, and Polacek [10][11], who determined the presence of vibrations in machine tools due to the modulation or regeneration of the chip thickness. In low stiffness conditions, a feedback phenomenon turns current vibrations into vibrations of greater amplitude for the following period. At this time, Tobias [12] and Merritt [13] developed the basic dynamic theory for vibrations in machining, distinguishing between the different types of chatter, A or B, depending on the direction of the mode with respect to the plane where chip is formed.

2. Vibration Prediction in Turning Processes

Tlusty [14] developed a one-dimensional orthogonal cutting model and obtained an approximate solution by projecting cutting forces and structural dynamics in the chip thickness direction. Later, Marui [15][16] carried out an experimental study where they concluded friction forces on the contact flank introduced energy on the cutting system and are responsible for maintaining the chatter vibration. Kaneko [17] proposed a 2D model for the prediction of chatter marks based on tests on a cantilevered piece. They were capable of relating the behavior of the rotating workpiece with a certain force, inversely proportional to the cutting speed and proportional to the velocity of the vibration, and studied the phase shift of the vibration. Minis [18] integrated the approach of the oriented transfer function with a cutting geometry in three dimensions but carried out the experimental validation for an orthogonal cutting. Then, he applied the Fourier series expansion to the periodic terms determining the Fourier coefficients of the corresponding milling transfer functions [19].

3. Experimental Techniques

3.1. Experimental Techniques for Chatter Avoidance

This sub-section deals with experimental techniques regarding the modification of cutting parameters during machining. For instance, spindle speed variation (SSV) technique can create a time-varying delay by creating distortions on chip thickness. As a result, new more favorable phase lags between inner and outer chip modulation reduce the chatter feedback mechanism [20][21][22][23]. There are different ways to vary the rotation speed of the head, but the most successful methods introduce a sinusoidal SSV, in which the speed of the spindle sinusoidally oscillates at a convenient frequency and amplitude [24][25].

The technique can be adapted to different cutting systems and dynamics. However, some areas in the stability lobe diagram that were previously stable can turn unstable when applying the variation. Another drawback of this technique is the high accelerations and decelerations in the spindle as well as the difficulty in tuning the frequency and amplitude of the variation.

3.2. On-Line Chatter Classification, Detection, and Monitoring

Before it is fully evolved, chatter identification at early stages is crucial for its suppression or minimization in real-time applications. For this purpose, the time-efficiency method for monitoring of vibration or/and process signals is a key issue to be embedded in CNC controllers and other external devices. Several techniques have been used for chatter recognition based on pattern recognition, for instance via support vector machine [26], sensor-less based on indexes of power-factor theory [27], topological data analysis, or the use of regression neural networks where non-linear effects need to be faced [28].

4. Conclution

Chatter is a known problem in turning and it can be approached in many different ways. This review resumes some of the efforts in the state of the art to detect, avoid, and reduce chatter vibrations and its harmful effects. First, the work was concentrated on analytical and numerical methods for stability prediction. However, whenever chatter is very complicated to model, active and passive techniques can be the answer. Therefore, a special section highlighted the milestones regarding these techniques.

After carefully examining research works, intense focus was and still is paid to mechanistic models. Numerical and mechanistic models are very popular and represent a relatively accurate way of predicting stability loss. In most cases, 1- or 2-DOF models establish the stability in turning processes. However, they lack generality. Research groups often face and solve a particular problem in a particular turning system. As chatter is a polyhedral problem, many authors tried to generalize the problem [29][30][31][32][33][34][35][36][37]. Systems having non-linear effects such as low cutting speeds, low machinability and hard materials, process damping, or wear are more complicated to model [38]. In these cases, chatter should be faced or completed through passive and active techniques. In recent years because of 4.0 Industry, acquiring and postprocessing many data sets at a high sampling rates is no longer an ideal task but a reality which should help designers to select suitable, productive but safe, cutting parameters.

As a general criterion, the stability of high speed turning and milling systems is investigated using a priori methods such as lobe diagrams. In this way, the spacing between low-order lobes can be advantageous for programming high depths of cut. However, this is not possible for turning processes and low spindle speeds, for instance when turning titanium or other low machinability alloys and superalloys. Chatter occurs at high order lobes where there is no spacing between lobes. Besides, process damping and nonlinearities hinder the modelling process. In those cases, practical techniques for chatter suppression such as SSV can be very interesting alternatives. While there is some reserve on the part of the industry when it comes to introducing spindle speed variation-SSV, machine-tool builders are beginning to sell machines with this capability.

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