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An active system of reduction of vibrations in a centerless grinding machine using piezoelectric actuators

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Abstract

Centerless grinding has been extensively used in production engineering to produce accurate cylindrical parts together with high productivities. On the other hand, regenerative chatter vibrations are one of the major problems that limit the ability to produce round workpieces. This constraint can be solved selecting proper machine setup conditions, which still largely relies on a trial and error method, and sometimes this approach is not optimum in a productivity sense. This paper shows a novel method to reduce chatter vibrations in a centerless grinding machine using actively controlled piezoelectric actuators. A simplified model of the machine is used to simulate the behavior of several commercially available piezoelectric actuators in two different locations of the machine. Based on these simulations, a selection of proper actuators and their optimal location is obtained and the control system is implemented experimentally. Experimental results show that the control strategy provides a stabilizing effect on chatter. Thus, the viability of using piezoelectric actuators as active components is demonstrated, providing an important advance in the knowledge of chatter control in centerless grinding machines.

Keywords: Centerless grinding; Piezoelectric actuators; Vibration reduction; Active damping

1. Introduction

One of the main reasons that makes difficult to attain the current requirements of precision and productivity related to machine tools is the appearance of vibrations during machining processes. As consequence, it is possible to find many studies about this subject. It is first important to get a major comprehension of the problem and of the involved factors. This would make possible to develop strategies to reduce the presence of vibrations during the machining processes.

Most of the carried out studies concerning the different types of vibration that appear during the machining process are devoted to the self-excited vibrations (chatter). Generally speaking, self-excited vibrations phenomena is the result of an interaction between the structural dynamics of the machine tool and the cutting process. As a result the machine vibrates basically at a frequency close to one of its natural structural modes, even without the presence of external acting forces.

Different researchers have elaborated models, specially adapted to particular machining processes, based on regenerative forces and the characterisation of the dynamic behavior of the machines [1–3]. This allowed to predict the limits of stability and the dynamic response of the machines [4–6].

Several approaches to reduce the influence of chatter have been developed. Some procedures try to obtain optimized machining work parameters, other implement passive reduction techniques (using elements that store or remove energy), and other introduce secondary sources of energy to the system.

At present, it is possible to find systems making use of piezoelectric actuators and implementing active control strategies to reduce vibrations. The operational characteristics

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of piezoelectric materials allow their integration in the structures of the machines, so that the structural damping is increased and the vibratory behavior is therefore improved [7,8].

The activity deployed in the frame of the presented work consisted in developing an active damping system, using piezoelectric actuators, to reduce the vibrations produced in frequency ranges close the natural frequency of vibration of the machine. The grinding machine behavior was simulated using a lumped parameter model. This machine model was used to define locations and required characteristics of the actuators. A proportional control with a second order filter was used. Next, the machine was modified to incorporate the selected actuators and, finally, several tests were carried out to evaluate improvements in the surface quality of the pieces and in the machine dynamic behavior.

2. Analysis of the centerless grinding process

In spite of being a wide spread industrial production process, grinding is one of the most complex and less known machining technologies due to the large number of involved variables. The analysis of cutting processes in which abrasive grains are involved is especially complex, due to the random character of the distribution of the edges of cut in the surface of the grinding wheel and their variable disposition produced by wear.

Among the diversity of grinding processes, centerless grinding is a chip removal process where the workpiece is not clamped, but it is just supported by the regulating (driving) wheel, the grinding wheel and the work blade. This configuration (Fig. 1) allows high precision finishing levels of cylindrical pieces combined with high productivity, but frequently roundness errors are produced, because no fixed axis in the workpiece exists. This makes centerless grinding process susceptible to suffer instabilities.

It is possible to operate in two different ways in a centerless grinding: through-feed and in-feed (plunge). In through-feed grinding, the workpiece rotates between the grinding wheel and the regulating wheel. One or both wheels of the centerless grinding machine are tilted from the horizontal plane, which creates a horizontal velocity component to the workpiece so that it moves axially while it is being grinded.

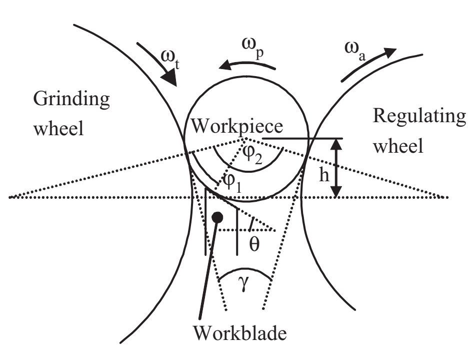

Fig. 1. The process of in-feed centerless grinding.

In-feed centerless grinding is similar to plunge grinding in a cylindrical grinding machine. Here, the workpiece is placed between the blade and the regulating wheel, which makes the workpiece to turn. Both move it into a programmed feedrate to complete the grinding process.

The obvious function of the grinding wheel is to remove material from the workpiece. Nevertheless the regulating wheel has a double function: on the one hand, it presses the workpiece against the grinding wheel, and on the other hand, it controls both the rotational speed and the axial advance of the workpiece.

2.1. Dynamics of the centerless grinding machine

The appearance of vibrations in centerless grinding machines is especially pernicious as grinding is a finishing process. These vibrations generate instability of the machining process, a poor surface finish, a significant wear of the wheels and important stresses in all the elements of the machine.

Different authors proposed analytical models for the centerless grinding process [6,9]. In these studies, it was established that instability in the centerless grinding process depends on: geometric factors, the dynamic characteristics of the machine and the machining process.

Geometric factors cause an instability problem when, under certain operation conditions, initial faults in the surface of the workpiece are reproduced and even increased as consequence of the deviations of the cutting point from the theoretical movements between the wheels and wokpiece.

On the other hand, regenerative chatter is the most important type of instability in the centerless grinding process. Unlike other processes, the waviness caused by chatter appears not only in the workpiece, but also in the wheels.

For a given machine, its tendency to vibrate depends on the correlation between the machining parameters and the dynamic flexibility of the machine. The selection of the suitable machining parameters for a given operation makes it necessary to carry out a significant number of tests, which depend on the experience of the users and are very time consuming. For this reason, it is preferable to increase the stability of the machine acting on its dynamical behavior.

The grinding machine used during present study was equipped with a 500 mm long and 650 mm in diameter grinding wheel. Fig. 2 shows a schematic view of the machine.

With the aim to determine the dynamic characteristics of the centerless grinding machine, an experimental modal analysis was carried out using impact testing technique in order to obtain the vibration mode shapes and frequencies.