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Monitoring single-point dressers using fuzzy models

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Abstract

Grinding causes progressive dulling and glazing of the grinding wheel grains and clogging of the voids on the wheel's surface with ground metal dust particles, which gradually increases the grinding forces. The condition of the grains at the periphery of a grinding wheel strongly influences the damage induced in a ground workpiece. Therefore, truing and dressing must be carried out frequently. Dressing is the process of conditioning the grinding wheel surface to reshape the wheel when it has lost its original shape through wear, giving the tool its original condition of efficiency. Despite the very broad range of dressing tools available today, the single-point diamond dresser is still the most widely used dressing tool due to its great versatility. The aim of this work is to predict the wear level of the single-point dresser based on acoustic emission and vibration signals used as input variables for fuzzy models. Experimental tests were performed with synthetic diamond dressers on a surface-grinding machine equipped with an aluminum oxide grinding wheel. Acoustic emission and vibration sensors were attached to the tool holder and the signals were captured at 2MHz. During the tests, the wear of the diamond tip was measured every 20 passes using a microscope with 10 to 100 X magnification. A study was conducted of the frequency content of the signals, choosing the frequency bands that best correlate with the diamond's wear. Digital band-pass filters were applied to the raw signals, after which two statistics were calculated to serve as the inputs for the fuzzy models. The results indicate that the fuzzy models using the aforementioned signal statistics are highly effective for predicting the wear level of the dresser.

Keywords: Dressing; Fuzzy logic; Wear; Grinding; Acoustic; Vibration

1. Introduction

Increasing interest has focused on the study and application of the grinding process, because it is the finishing process most widely used in the metal and mechanical industry to machine workpieces with better surface quality and tight tolerances. Moreover, the ever expanding use of CNC grinding machines in the industrial sector makes it increasingly necessary to study the process as it pertains to automation capacity.

Despite the advances achieved in research to eliminate problems that affect the normal operation of grinding machines, which generally cause stoppages and require corrections to be made by an experienced operator, usually manually, many problems still need solutions. This is due mainly to the high complexity of the process, which results from the numerous variables involved.

Dressing, on the other hand, is the operation of conditioning the surface of the grinding wheel to restore its original profile and reestablish the characteristics of sharpness that were lost due to wear during the grinding process. This operation is responsible for producing a satisfactory topography on the grinding wheel, which has a significant impact on the total grinding force, energy, temperatures, wheel wear and finish of ground surfaces [1].

However, dressing tool (dresser) wear has a stronger effect on the surface roughness of the workpiece than do other parameters of the grinding process, such as the depth of cut and feed velocity [1]. According to Habrat in the writings of Martins et al. [2], monitoring the wear of the tip of the dresser will allow for adequate control of the grinding process in terms of required workpiece roughness.

The sensors most commonly used to monitor machining processes are force, power, acoustic emission (AE) and

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vibration sensors, which have become increasingly present in manufacturing plants that strive to improve their quality and productivity. When handled properly, the data collected by sensors can provide information required for the accurate diagnosis of problems in machines and processes, as well as real analyses of the productivity and status of production, for example.

Artificial intelligence models have been designed to estimate or predict important parameters of machining processes, using as inputs signals collected by one or more sensors and parameters derived from these signals. In the case of fuzzy logic, according to Pham and Pham [3], these models reflect the qualitative and inexact nature of human judgment, and thus make specialized systems more flexible. In fuzzy logic, the precise value of a variable is replaced by a linguistic description represented by a fuzzy set, and inferences are made based on this representation.

This article contributes by presenting a methodology to estimate the wear of single-point dressers based on acoustic emission and vibration signals and fuzzy models. It is an extension of the work of Martins et al. [2], which used only acoustic emission signals and neural models for estimating dresser wear.

One of the reasons for the development of this work was the possibility of creating a model more closely resembling the language used by machining operators to refer to monitored wheel dresser wear. This motivation is based on the work of Shaw in Ali and Zhang [4], who report that a production operation does not require an absolute model that can deliver high accuracy, since such a model is not reproduced in practice. What is needed, according to the authors, is a “relative” model that can provide general guidelines for the user about what to do and how to do it. The reason for this is that there will always be some degree of trial and error on the shop floor, so a relative model serves as a good starting point.

2. Monitoring the Dressing Operation

Dressing conditions can strongly influence the performance of the grinding operation. To exemplify this influence, suffice it to say that grinding forces can vary by about 500% simply by varying the dressing conditions in the same type of operation [5].

The efficiency of the grinding operation is highly dependent on the grinding wheel surface. However, Badger [6] reported that thermal damage during the grinding process can be reduced significantly by adopting correct operating parameters and dressing strategies.

The dressing process can be monitored to produce consistent grinding wheel surface quality. The service life of the grinding wheel can be defined by monitoring changes in the characteristic amplitude and frequency of the acoustic emission signal [7]. However, the market still lacks devices that can evaluate the grinding wheel surface during the grinding operation in a manufacturing environment.

The use of acoustic emission to monitor the grinding process has been a subject of research since 1984. One of the first conclusions of these researches was the high sensitivity of the root mean square (RMS) value of the AE signal in detecting contact between the grinding wheel and workpiece [8]. Other parameters and/or statistics of the raw AE signal are reported in the literature. A statistic that has been employed successfully to estimate dresser wear is the ratio of power (ROP) of the AE signal [2], which is defined by equation (1).

$$ROP = \frac{\sum_{k=n_1}^{n_2} |X_K|^2}{\sum_{k=0}^{N-1} |X_K|^2} \quad (1)$$

where X_k is the *k-th* discrete Fourier transform, n_1 and n_2 are values that define the frequency range to be analyzed, and N is the size of the AE data block. The denominator of the equation eliminates the effect of local power.

On the other hand, vibration (acceleration) signals are rarely used to monitor the process, perhaps due to the lack of researchers interested in exploring the characteristics of this signal in the grinding and dressing processes, or the mistaken belief that the vibration signal will always be influenced by frequencies deriving from ambient noise and other processes. The vibration sensor captures the vibrations produced by cyclic variations in the dynamic components of cutting forces. Metal cutting processes emit free, forced, periodic and random vibration signals. It is difficult to measure vibration directly because the vibration mode is frequency dependent. Therefore, measurements are taken by means of vibration-related parameters, such as the rate at which the dynamic forces change per unit time (acceleration), and the characteristics of the vibration are extracted from the patterns thus obtained [9].

Several studies have focused on correlating the vibration signal with the characteristics of machining processes. For example, Hassui et al. [10] showed that the RMS signal of workpiece vibration is better correlated with grinding wheel wear than the acoustic emission signal. Furthermore, the sensitivity of the vibration sensor is as good as that of the acoustic emission sensor in detecting the moment of contact between the grinding wheel and workpiece and the end of spark-out. Hassui and Diniz [11] examined the ability of the vibration signal to perceive variations in workpiece roughness and roundness, and hence, the feasibility of its use in defining the moment of dressing. Their findings indicated a good correlation between vibration signals and the roughness and condition of the grinding wheel.

Other studies have been published about monitoring the dressing operation, but only a few studies have focused on the wear of single-point dressers. Shin and Zhang [12] studied the wear properties of single-point dressers in laser-assisted truing and dressing of vitrified CBN grinding wheels. Their experimental results indicated that dresser wear rates depend on laser power, dressing depth, and feed rate. The authors also concluded that the heating history influences dresser wear to some extent. The work of Habrat and Porzycki [13] describes an optical monitoring system for measuring the equivalent radius of the diamond dresser, and makes inferences about its wear. Martins et al.’s work [14] describes a study to classify