Journal of Manufacturing Processes 31 (2018) 199–213

Contents lists available at ScienceDirect

Journal of Manufacturing Processes

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

Full Length Article

In-process tool condition monitoring in compliant abrasive belt grinding process using support vector machine and genetic algorithm

Vigneashwara Pandiyan[a], Wahyu Caesarendra[b], Tegoeh Tjahjowidodo[a,*], Hock Hao Tan[a]

[a] School of Mechanical and Aerospace Engineering, Nanyang Technological University, 639798, Singapore
[b] Rolls-Royce@NTU Corporate Lab, 65 Nanyang Avenue, 637460, Singapore

ARTICLE INFO

Article history:
Received 18 May 2017
Received in revised form 7 November 2017
Accepted 13 November 2017

Keywords:
Abrasive belt grinding
GA
Tool wear
Condition monitoring
SVM

ABSTRACT

Industrial interest in tool condition monitoring for compliant coated abrasives has significantly augmented in recent years as unlike other abrasive machining processes the grains are not regenerated. Tool life is a significant criterion in coated abrasive machining since deterioration of abrasive grains increases the surface irregularity and adversely affects the finishing quality. Predicting tool life in real time for coated abrasives not only helps to optimise the utilisation of the tool's life cycle but also secures the surface quality of finished components. This paper describes the evolution of the abrasive grain degradation in the belt tool with process time and also the development of Support Vector Machine (SVM) and Genetic Algorithm (GA) based predictive classification model for in-process sensing of abrasive belt wear for robotized abrasive belt grinding process. With this tool condition monitoring predicting system, the effectiveness of the belt and the surface integrity of the material is secure. The analysis of sensor signals generated by the accelerometer, Acoustic Emission (AE) sensor and force sensor during machining is proposed as a technique for detecting belt tool life states. Various time and frequency domain features are extracted from sensor signals obtained from the accelerometer, acoustic sensor and force sensor mounted on the belt grinding setup. The time and frequency domain features extracted from the signals are simultaneously optimised to obtain a subset with fewer input features using a GA. The classification accuracy of the k-Nearest Neighbour (kNN) technique is used as the fitness function for the GA. The subset features extracted from the signals are used to train the SVM in MATLAB. An experimental investigation using four different conditions of tool states is introduced to the SVM and GA for the prediction and classification. By the experimental results, this research proves that the proposed SVM based in-process tool condition monitoring model has a high accuracy rate for predicting abrasive belt condition states.

1. Introduction

Coated abrasive tools in the form of a disk, flap wheel and belt are widely used in the industry for tertiary finishing operations. An important aspect of the coated abrasive tools is their compliance as illustrated in the Fig. 1. The tool deforms in conformity with the surface of work coupon due to a polymer backing when it comes in contact without modifying its nominal shape and at the same time achieving required material removal.

Abrasive belt grinding is a two-body abrasive compliant machining process used to improve the surface finish of components. The belt grinding system consists of thermosetting polyurethane elastomer contact wheel that can be deformed to assist the coated abrasive belt to fasten around it which functions as cutting edge that makes it be a compliant tool. In recent years, belt grinding system consisting of a robot arm and coated belt grinding abrasive tool, has emerged as a finishing process for machining surfaces with complicated geometry like turbine blades. Like any other abrasive machining, grinding belt topography features such as grain distance, grit size, and wear rate impacts the final ground surface quality [1]. The life cycle of a coated abrasive belt tool vitiates due to continuing grain wear resulting to tool failure. As the abrasive belt tool approaches the end of its life, the degradation in the surface quality of the machined workpiece is quite apparent. Many aspects of the interactions between cutting tool, workpiece, and material removal during compliant belt grinding are not fully understood due to high nonlinearity of the process. The granularity

* Corresponding author.
E-mail addresses: TTEGOEH@ntu.edu.sg, tegoeh.tjahjowidodo@gmail.com (T. Tjahjowidodo).

https://doi.org/10.1016/j.jmapro.2017.11.014
1526-6125/

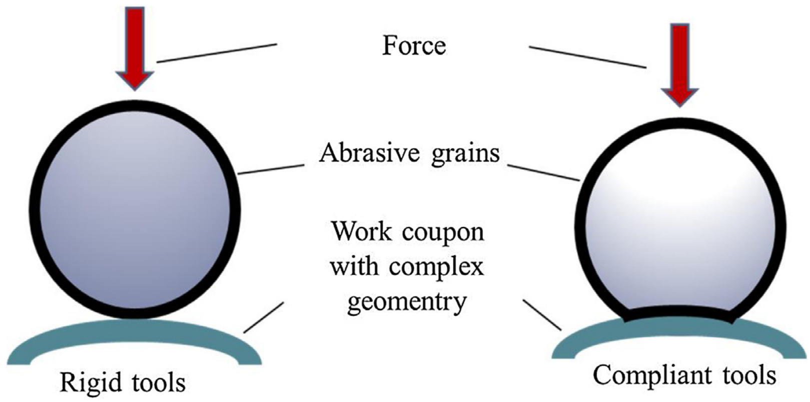

Fig. 1. Comparison of contact characteristics of rigid and compliant tools.

of the abrasive grain is dominant among all process parameters for material removal in belt grinding process [2]. The pre-planned tool replacement methodologies are no longer suitable in belt grinding process as the machining conditions vary extensively. The decrease in the material removal rate due to belt wear was compensated by increasing the abrasive belt speed and decreasing the workpiece feed rate [3]. A linear mathematical model was proposed which stated that the overall material removal rate is proportional to belt wear factor [4]. A reliable real-time monitoring system could allow ideal exploitation and identification of the tool life states and avert these problems.

The idea of tool life monitoring has earned vital importance in any manufacturing industry. This is mainly due to the conversion of the manufacturing stations from physically operated production machines to highly automated robotic manufacturing cells. Thus, there is an immense need for tool life monitoring systems to confirm the best performance of the unsupervised machining stations. Sensing techniques for tool condition monitoring are classified into two categories namely direct sensors and indirect sensors [5]. Direct methods have the benefit of delivering a direct and accurate evaluation of the tool's state but are constrained to in-cycle deployment because cutting edges are mostly unreachable during machining. However in the case of indirect methods, process parameters such as temperature, vibration, cutting forces, AE, etc. are calculated successively, and tool states are assessed based on reliable signal patterns which can be correlated to tool wear states.In the case of unsupervised machining stations, an appendage of sensor capabilities can extremely reduce downtime and augment product quality. Experiments have been performed to study effects of tool wear on cutting force signals when drilling copper alloy to achieve on-line drill wear monitoring [6]. The correlation between flank wear and average tangential cutting force coefficient were used with cutting parameters such as cutting speed, depth of cut and feed per tooth to evaluate tool wear for milling [7]. A time series modelling technique was developed to extract features such as autoregressive parameters, the power of the AE signal and AR residual signals for monitoring coated carbide tool conditions based on AE signals obtained during machining of C-60 steel and were found that these features were sensitive to wear rate [8]. These works on tool wear monitoring were focused on time series and frequency domain analysis. Wherein, an upper limit is set among the normal and abnormal states of the tool. Conversely, the threshold value changes with time and cutting environment which makes these techniques in-accurate. For increasing the performance, more novel logics, such as pattern recognition and statistical techniques have been developed in the region of tool wear assessment. A neural network-based sensor fusion model for estimation of the average flank wear of the primary cutting edge based on features isolated from the fused data of some machining zone signals such as cutting forces, spindle vibration, spindle current, and sound pressure level has also been investigated [9]. A new modelling outline for tool wear monitoring in using Hidden Markov Models (HMMs) based on feature vectors extracted from the vibration signals calculated in turning operation of AISI 8620 steel has also been proposed [10]. The exact moment at which abrasive grinding wheel wears to accomplish the dressing process was determined by vibration and AE sensor [11]. A virtual verification system for grinding wheel condition monitoring by use of a neural network and fuzzy logic was developed by blending vibration, AE and grinding forces sensor outputs [12]. AE and force signals have been used for classifying the tool conditions into four distinct classes namely sharp tool, used tool, chip noise, and tool breakage using pattern recognition [13]. Most of the previous research work on tool wear monitoring was on hard tools with defined cutting edges and rigid grinding tools using sensors and decision-making algorithm as listed in Table 1. Tool condition monitoring has not been concentrated on the compliant tools, to bridge this gap the proposed research tries to develop a methodology for condition monitoring and predicting tool wear in compliant belt grinding process.

Though not much work has been explored in tool wear of coated belt abrasive tools, other works on coated abrasive tools provide some insight.A real-time complimentary multi-sensor integration system to predict surface roughness of the work coupon in belt grinding process based on contact conditions was developed using SVM based classification algorithm [14]. A removal control method for the belt grinding process through the optimised dynamic parameters of the robot was proposed using an adaptive model based on statistic machine learning [15]. The changes of grinding force and metal removal rate with time in coated Abrasive belt grinding are caused principally by the formation and increase of the worn flat area on grain tips [16]. The influence of abrasive grain's wear and contact conditions on surface texture in belt finishing process and concluded that material removal rate changes based on the wear level of active grains and becomes stable after the effective contact duration [17]. There have been studies on the influence of the effects and the interactions of the belt finishing parameters such as abrasive film parameters, cutting parameters on the surface texture. The study proved that amid the parameters of belt finishing, the granulometry of abrasive films is the highly significant parameter on surface finish and quality [18].

These studies on belt grinding process emphasise on the impact of tool condition monitoring in the effectiveness of the machining process and surface finish. As tool grain wear has a direct influence on the uniform material removal, monitoring such coated abrasive tool condition in real time helps in quality control of surface in finished components. This research tries to predict the belt