Measurement 94 (2016) 71–79

Contents lists available at ScienceDirect

Measurement

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

Monitoring of through-feed centreless grinding processes with acoustic emission signals

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ARTICLE INFO

Article history:
Received 5 December 2015
Received in revised form 25 May 2016
Accepted 25 July 2016
Available online 27 July 2016

Keywords:
Centreless grinding
Acoustic emission
Wavelet

ABSTRACT

Grinding is a mechanical removal process applied mainly in finishing operations of hardened workpieces to produce small tolerances with high-quality. Especially, centreless grinding is broadly used in serial production due to the requirement of high accuracy in process. Centreless grinding is used to produce several mechanical components such as, bushings, needles, ball bearings, valves, and stems for shock absorbers. However, the setup of machine tools is very complex and needs long time due to the great number of input variables that should be checked and configured. The acoustic emission monitoring can be used to help the first setup or during the grinding process becoming a on-line detection system. Considering the importance of obtaining an efficient methodology to predict and detect the surface quality and the dimensional errors, a monitoring of the frequency on the spectrum of acoustic emission (EA) was conducted, related to surface roughness Rz, cylindricity, and roundness. The FFT and Wavelet were applied aiming to help the analysis of data and provide the best understanding of the signal and generating an intelligent information in the automation in grinding process. Thus, in this work the results showed that the analysis of the harmonic content of acoustic emission signal is a powerful tool to monitoring the centreless grinding process.

1. Introduction

The direct measurement of normal and tangential forces in grinding is important to understand the static and dynamic behavior of the machine tools and cutting process. However, the direct measurement in grinding depends on a great number of input parameters that are difficult to be evaluated and defined simultaneously [1]. Generally, the well-known parameters are associated with grinding wheel life, cycle times, and quality of workpieces. Based on this, to demonstrate the influence of these parameters most often such parameters are studied separately [2,3].

The definition of the exact point to remove the worn grinding wheel from machine tool or change the cutting conditions aiming the process optimization are challenges that depend on the intervention of operators and their ability. The development of a monitoring system and process control on-line is fundamental to obtain a complete automation in grinding process. Thus, it can be integrated and flexible with manufacturing systems without human interference.

Inasaki [4] comments that the most important objective during the monitoring of a grinding process is to detect the breakdowns that occur during the cutting. Furthermore, it is necessary to provide exact information to optimize the process and generate an efficient database to determine the best adjusts of input parameters. However, Johnson [5] supports that the main objective is the arrangement of input parameters maintaining them in range of reference values.

Among several manufacturing processes, grinding can be considered as one of the most important process in modern industry. Mechanical components that need high finishing and elevated quality have in one or more regions surfaces where the grinding process is applied. In the modern industrial production, the centreless grinding is the most used process, because it shows considerable flexibility and low time to produce a great batch of mechanical pieces. Centreless grinding is an abrasive process that uses grits with undefined geometry and elevated complexity due to the great number of input variables in its setup [6,7].

The difficulty to control the damages generated in grinding process also is high due to the lack of a reliable method to provide an online support during the process [8]. Acoustic signals have been applied with success to determine changes in quality parameters such as surface roughness and roundness errors [9]. The acoustic emission signal when filtered can enable the

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http://dx.doi.org/10.1016/j.measurement.2016.07.075
0263-2241/

implementation of a real time control system, providing an optimized centreless grinding process [10–13].

The acoustic emission signal is based on the detection of elastic transient stress waves generated due to the released quickly energy in the rearrangement of the internal microstructure of a material that was submitted to an external impulse [14]. These stress waves produce displacements in the material surface that are detected by a piezoelectric sensor converting these displacements in electrical signals [15]. The acoustic emission captures high-frequency signals, in a range of 50–1000 kHz, which are signals above the noise generated by the grinding process [16]. Based on this, acoustic emission is a sensible and extremely adequate methodology in the monitoring of grinding process that removes chips with very small dimensions [17].

Webster et al. [18] affirms that the detection of acoustic emission signal is significantly more sensitive to changes in grinding cutting conditions than the measurements of force and power cutting. It also offers a more promising method for online monitoring of the process.

Acoustic emission can be registered in large-scale in the case of seismic events or in small-scale as the displacement in the microstructure of deformable materials. However, other events as corrosion in tanks of oils, electrical discharges, crack growth in glasses, and plastic deformation of metals can be evaluated by acoustic emission signals [19]. Furthermore, mechanisms of deformation and fracture, which occur in metals, such as crack formation, displacement of grain boundaries, fracture, and inclusions, can also be registered by acoustic emission signals [20]. The signal response of a material depends on its microstructure and how the deformation occurs and based on this, it can be expected a great range for the acoustic emission signals.

Brittle materials and heterogeneities are factors that generated a high emissivity, well-defined peak and high amplitudes. Ductile deformation mechanisms such as coalescence of micro cavities in ductile metals are associated with low emissivity, more scattered peaks, and low amplitude [21]. In the grinding process, the primary sources of acoustic emission are the formation of cracks, friction between the grain and the workpiece, the elastic impact, scratching without chip removal, removal and breaking of the grain, binder removal, and heat induction caused by microstructural changes.

Inasaki [22] affirms that in dressing operation the acoustic emission signal can be used to define the behavior of grinding process, because the increase of depth of cut and dressing speed generates an increase in surface roughness of workpiece and acoustic emission signal. Dressing is a process that assures a stable grinding operation, because it rectifies the surface of grinding wheel. Thus, metallic and non-metallic inlays that occur on the face of the grinding wheel and breaking the abrasive grit are corrected satisfactorily.

Vieira [23] developed a monitoring system to identify failures occurred during the dressing operation. The new methodology generated a digital map of the grinding wheel surface, which was based on acoustic information recorded during the centreless grinding. The system had an acoustic sensor and an inductive sensor of proximity for the synchronization of the start of acquisition. The acoustic signals were used to obtain a 3D graphic and the numerical representation generated a matrix with RMS values from the acoustic emission signals recorded during the grinding. The results showed a great potential throughout the mapping system to detect and diagnose problems that occurred during grinding and dressing processes.

Rascalha et al. [6] developed a monitoring of spindle operation using a load cell. The results demonstrated that it is possible to understand not only the geometry of grinding wheel but also its surface generated after dressing an effective methodology to define the surface quality and dimensional errors is presented. Thus, it was conducted a monitoring of the frequency spectrum of the acoustic emission signal and its relation with the surface roughness Rz, cylindricity error, and roundness error. Based on this, this work shows an analysis of harmonic content of the acoustic emission signal in centreless grinding through the fast Fourier transformed. The main aim was contributing for intelligent automation in centreless grinding process.

2. Methodology

Experimental tests were carried out in a through-feed centreless grinder model RK 350-20 manufactured by Cincinnati Milacron in the shop floor of an auto parts industry, as it can be seen in Fig. 1. The tool was a resinoid grinding wheel with 609 mm of outer diameter, 508 mm of length, and 304 mm of inner diameter. The regulating wheel had 355 mm of outer diameter, 508 mm of length, and 152 mm of inner diameter. The spindle speeds were 1800 rpm and 70 rpm for grinding wheel and regulating wheel, respectively. An emulsifiable oil type ECOCOOL P1978 with refraction factor of 1.7 was used as cooling system. The output of the cooling system was 190 l/min with a range of 6–8% of oil concentration acting into the grinding gap. The concentration was analyzed using a refractometer model N1-E Brix 0–32% made by ATAGO.

The work-rest used to the displacement of the workpieces between regulating wheel and grinding wheel had an inclination of 20°. The feed rate of workpieces was 5000 mm/min. The acoustic emission sensor was assembled at the side of work-rest, according to Fig. 2.

Fig. 1. Through-feed centreless grinder model Cincinati RK 350/20.