Quantitative Analysis of Grinding Wheel Loading Using Image Processing

Vipin Gopan*a, Leo Dev Wins K*b

aKarunya School of Mechanical Sciences, Karunya University, Coimbatore-641114, India
bKarunya School of Mechanical Sciences, Karunya University, Coimbatore-641114, India

Abstract

Grinding is an abrasive machining process which can produce very fine surface finishes. The removed chips from the workpiece which get welded to the porosities between the abrasive grains can adversely affect the final surface finish of the machined component. Quantitative analysis of wheel loading can provide information about the cutting conditions of the wheel. With the development in the field of machine vision and image processing, this study focuses on developing a system for the quantitative assessment of wheel loading using image capturing and image processing. Images of the grinding wheel were acquired using microscope with a magnification of 20x. Image segmentation by global thresholding technique was utilized for segmenting the loaded portions from the rest of the wheel. Experimental results presented show the feasibility of the proposed system in the quantitative assessment of grinding wheel loading.

© 2016 The Authors. Published by Elsevier Ltd. This is an open access article under the CC BY-NC-ND license (http://creativecommons.org/licenses/by-nc-nd/4.0/).

Keywords: Grinding wheel, Machine vision, Image segmentation, Global thresholding, Wheel loading

1. Introduction

The abrasive particles present on the surface of the grinding wheel are responsible for producing fine surface finishes on the workpiece. During the grinding process, the removed chips from the workpiece get accumulated to the porosities between the abrasives, which is called as wheel loading. Cutting force and temperature increase with wheel loading which in turn accelerate the wear of the grinding wheel. As a whole, the surface finish of the workpiece deteriorates. In order to attain the original cutting capability of the wheel, it is necessary to carry out the dressing operation. Since the wheel dressing is a time consuming process, it is necessary to optimize the wheel dressing intervals. Therefore monitoring the condition of the grinding wheel for wheel dressing has got its significance.

* Corresponding author. Tel.: +91-8891710248;
E-mail address: vipingopan123@gmail.com

2212-0173 © 2016 The Authors. Published by Elsevier Ltd. This is an open access article under the CC BY-NC-ND license (http://creativecommons.org/licenses/by-nc-nd/4.0/).
Peer-review under responsibility of the organizing committee of RAEREST 2016
doi:10.1016/j.protcy.2016.08.198
Many of the research works for the condition monitoring of the grinding process have been carried out by using techniques such as neural networks and fuzzy logic by measuring acoustic emission signals, cutting power signals, eddy current etc. Nakai et al. measured the wear of the grinding wheel using intelligent systems composed of four types of neural networks [1]. Acoustic emission and cutting power signals were acquired and tool wear was measured by imprint method throughout the tests. Warren Liao et al. used acoustic emission signals for the condition monitoring of grinding process [2]. AE signals were collected when the wheel was sharp and when the wheel was dull. Discrete wavelet decomposition procedure was used to extract discriminative features. Mokbel et al. used AE signals for monitoring the condition of diamond grinding wheels [3]. An acoustic emission sensor was attached to the mild steel specimens and raw AE signals generated from the grinding wheel/specimen contact were then analyzed using a fast Fourier transform. Lezanski et al. monitored the condition of grinding wheel based on neural network and fuzzy logic based system [4]. For each measuring signal, a few statistical and spectral features were calculated and used as input for data selection and classification procedures.

Several researchers have used machine vision systems and image processing for measuring the grinding wheel wear. Abdalslam et al. developed a non-contact three-dimensional wheel scanning system for measuring and characterizing the surface topography of grinding wheels [5]. Narayaperumal et al. evaluated the working surface of the grinding wheel using speckle image analysis [6]. A simple speckle imaging arrangement was fabricated and fitted into the grinding machine to capture the images of the grinding wheel and speckle image intensity distribution captured the changes in the grinding wheel surface condition. The image processing techniques, including segmentation and blob analyses were able to extract the cutting edge density, width, spacing and protrusion height from the surface topography measurements. Chang et al. measured the characteristic parameters of form grinding wheels used for microdrill fluting by computer vision system [7]. The edge detection, the straight line detection, the contour separation, the circular arc fitting, and the circular arc angle evaluation were the five sequential steps used for the measurement. Tarng et al. measured the wear of the grinding wheel using machine vision system [8]. SEM was used for capturing the images and edged detection technique was used in image processing for the wheel wear measurement. Lachance et al. measured the grinding wheel wear using machine vision system [9]. Binary segmentation technique was used for image processing. Fan et al. measured the wear of the grinding wheel using computer vision system [10]. Binarisation technique was used for image processing and ‘mapping function method’ was used to transform an image pixel coordinate to a space coordinate. In most of the machine vision systems for the condition monitoring of grinding wheel either a scanning electron microscope or optical microscope was utilized for capturing the images. SEM is highly accurate and can give very high magnifications so that surface conditions of the wheel can be monitored accurately. But it is very expensive and also wheel needs to be dismantled from the machine for inspection. Similar is the case with optical microscope. Also most of the works in this area are concentrated on the qualitative assessment of the grinding wheel condition.

Less work has been reported in the quantitative measurement of wheel loading. The present work focuses on developing a machine vision system for the quantitative measurement of the wheel loading. Image capturing was carried out using USB microscope with high resolution with an inbuilt LED source, so that there is no need to dismantle the wheel from the grinding machine for measurement and also is less expensive.

2. Experimental setup

Experiments were conducted on surface grinding machine with silicon carbide (SiC) wheel. Specifications and parameters of grinding are given in Table 1.

<table>
<thead>
<tr>
<th>Table 1. Specifications and parameters of grinding</th>
</tr>
</thead>
<tbody>
<tr>
<td>Machine</td>
</tr>
<tr>
<td>Grinding wheel</td>
</tr>
<tr>
<td>Coolant</td>
</tr>
<tr>
<td>Speed</td>
</tr>
<tr>
<td>Feed</td>
</tr>
<tr>
<td>Depth of cut</td>
</tr>
</tbody>
</table>
The digital images of the wheel surface are captured using USB microscope. Fig. 1 shows the schematic diagram of experimental setup for wheel loading measurement. Images of the topography of grinding wheel were taken using Veho USB microscope with a magnification of 20X. Illumination is provided by the means of LEDs provided within the microscope. A knob provided on the microscope is used for adjusting the brightness of illumination.

![Schematic diagram of experimental setup.](image)

### 3. Principle of measurement

The magnified images of the topography of the grinding wheel can provide complete information about the chip accumulation. Intensity of the light reflected from the chips which are accumulated between the abrasives is different from the rest of the wheel surface. This difference in intensity of light reflected is extracted for segmenting the loaded portions of the wheel. Digital images are captured and then converted to grayscale images. Gray scale images have light intensity varying from 0-255, where 0 corresponds to black and 255 corresponds to white. Image segmentation by global thresholding technique was used for image processing. A proper threshold range corresponding to good portions of the wheel was selected by analyzing the histogram of the fully dressed wheel. By setting that threshold range, all the pixels between those threshold ranges were converted to black pixel, while the remaining pixels were converted to white pixel. White pixels correspond to the loaded portion of the wheel. By counting the number of white pixels and dividing with the total number of pixels gives the percentage of wheel loading.

### 4. Selection of threshold range

The difference in the intensity of the light emitted from the abrasive grains and that of the chips accumulated on the wheel were used for setting the range of threshold value for image processing. Initially the grinding wheel was fully dressed to bring it to the best cutting condition. The images of the topography of the fully dressed wheel were taken and then converted to a grayscale image. The microscopic image of the fully dressed wheel is shown in the Fig. 2. The histogram of the grayscale image was then obtained. The histogram of the gray scale image is as shown in the Fig. 3. From the histogram of the fully dressed wheel it is clear that the intensity of the light reflected from the abrasive grains is in the range of 95 and 175. So threshold value between 95 and 175 corresponds to the good portion of the wheel. Any pixel value which falls outside this range is because of the chip accumulation and that corresponds to loaded portion of the wheel. Image segmentation can be carried out using 95 and 175 as the range of threshold values. Any pixel value which falls within this range was converted to black pixel which corresponds to good portion of the wheel and those pixel values outside this range was converted to white pixel which corresponds to loaded portion of the wheel.
5. Experiment

Experiments were conducted with mild steel as the specimen. The parameters set for grinding operation were, speed 2500rpm, feed 0.06mm/rev and depth of cut 0.1mm. Grinding wheel was fully dressed using diamond dresser and image of the cutting surface of the wheel was taken using microscope. Setup for capturing the images is shown in the Fig. 4. Grinding wheel was put into operation for next 80 minutes and images were taken for every 10 minutes interval. These magnified images were then processed using Matlab software. By using global thresholding technique, binary images were created with loaded portion in white pixels and rest of background in black pixels.
6. Results and discussions

The actual image and processed image of fully dressed wheel is shown in the Fig. 5. The white spots on the processed image indicate the loaded portions of the wheel. There are very few white spots on the dressed wheel which are obvious as when the wheel is in dressed condition no loading would have taken place. As the grinding operation continues, chip accumulation keeps increasing and the white spots on the processed images also increase. Actual and processed images of the grinding wheel after twentieth and eightieth minutes are as shown in the Fig. 6 and Fig. 7 respectively. Percentage of wheel loading after twentieth minute was 15.13% and the same after eightieth minute was 35.52%.

![Fig. 5. (a) actual image of the fully dressed wheel; (b) processed image of the fully dressed wheel.](image1)

![Fig. 6. (a) actual image of the grinding wheel after twentieth minute; (b) processed image of the grinding wheel after twentieth minute.](image2)

![Fig. 7. (a) actual image of the grinding wheel after ninetieth minute; (b) processed image of the grinding wheel after eightieth minute.](image3)
Percentage of wheel loading after every 10 minutes of operation is shown in the Table 2. Values presented clearly show that percentage of wheel loading keeps increasing with time. A graph with time versus percentage of loading is shown in Fig. 8.

Table 2. Percentage of wheel loading after every 10 minutes of operation.

<table>
<thead>
<tr>
<th>Time in minutes</th>
<th>Number of white pixels</th>
<th>Number of black pixels</th>
<th>Percentage of wheel loading</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 (dressed)</td>
<td>834</td>
<td>77566</td>
<td>1.06</td>
</tr>
<tr>
<td>10</td>
<td>11868</td>
<td>66532</td>
<td>15.13</td>
</tr>
<tr>
<td>20</td>
<td>13429</td>
<td>64971</td>
<td>17.12</td>
</tr>
<tr>
<td>30</td>
<td>17274</td>
<td>61126</td>
<td>22.03</td>
</tr>
<tr>
<td>40</td>
<td>19119</td>
<td>59281</td>
<td>24.38</td>
</tr>
<tr>
<td>50</td>
<td>20463</td>
<td>57937</td>
<td>26.10</td>
</tr>
<tr>
<td>60</td>
<td>22458</td>
<td>55942</td>
<td>28.64</td>
</tr>
<tr>
<td>70</td>
<td>26365</td>
<td>52035</td>
<td>33.62</td>
</tr>
<tr>
<td>80</td>
<td>27855</td>
<td>50545</td>
<td>35.52</td>
</tr>
</tbody>
</table>

Fig. 8. Percentage of wheel loading Vs Time

7. Conclusion

The experimental results presented show the feasibility of using the proposed system for the quantitative analysis of wheel loading. Image segmentation by global thresholding was used for differentiating the loaded portion of the wheel. Images captured with a magnification of 20x provided clear information about the cutting surface of the wheel. Experimental results proved that chip accumulation keeps increasing with time. The measurement was carried out with reasonable accuracy. Errors can be further eliminated by including noise filtering techniques during the image processing.

References


