Monitoring of Gear Surface Roughness in Angle Grinder using Vibration Analysis

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Abstract. This paper aims to provide the relation between surface roughness of angle grinder towards vibration amplitude. Prolong usage of angle grinder over excessive force will affect the performance of angle grinder where it tends to vibrate due to surface roughness of gear and create excessive vibration that will lead to hand-arm vibration system. Therefore, this study is conducted to investigate surface roughness of the gear teeth of angle grinder affects the amplitude of vibration. The amplitude of the vibration for angle grinder is conducted by using LMS data acquisition system. Meanwhile, the roughness of the gear teeth is measured by using Keyence Laser Confocal Microscope. The data was taken by every 100 hours of grinding process. The results show that the surface roughness of the gear teeth is steadily decreasing due to contact between gears and subsequently resulted increasing the amplitude of the vibration. For 500 hours measurement, the correlation of surface roughness of gear teeth with the amplitude of vibration is 93.7% for marked tooth and 86.5% for adjacent tooth, this indicates the strongest possible agreement that when surface roughness of the gear teeth decreasing, the vibration amplitude is higher.

1. Introduction

This project is specifically focusing on gear’s roughness in the angle grinder; bevel gear. Rotating machinery produces vibration during its normal operation as a consequence of friction and centrifugal forces of both the rotating parts and the bearings. The contacts of disc grinder with the workpiece generate excitation force that can affect the component such as gear, motor and bearing assembly. With frequent use of angle grinder in fabrication activities, the gears interaction will result in surface roughness and subsequently generate high level of vibration. The effects of the friction toward the gear assembly produce surface roughness of the gear over the length of time used. Monitoring the gears roughness is very important to determine the tendency of high vibration level in grinder. Trend analysis is used to analyse the relation of surface roughness and vibration amplitude. Trend monitoring of vibration level is a more useful maintenance tool than a one-time survey of the absolute magnitudes of features only. A slight linear increase of feature values turns to exponential when the point of failure is approaching. The time of failure depends strongly on machines and the stress caused by operating conditions. The paper is divided into different section, each dealing with various aspects of the subjects: it begins with a summary of review of vibration analysis, surface roughness measurement and followed by general overview of gear. The gear monitoring technique in angle grinder is discussed in detail which is vibration analysis. One of the major areas of interest in the modern-day condition monitoring of rotating machinery is that of vibration. If a fault developed and goes undetected, then, at best, the problem will not be too serious and can be remedied.
quickly and cheaply; at worst, it may result in expensive damage and downtime, injury, or even loss of life. By measurement and analysis of the vibration of rotating machinery, it is possible to detect and locate important faults such as mass unbalance, gear faults, misalignment, and crack.

2. Literature Review
The aim of this section is to provide the reader with an understanding of the gear system, vibration analysis and gear surface roughness measurement.

2.1. Vibration Monitoring Methods
Vibration monitoring is one of the main tools that allow determining the mechanical health of various components of a machine in a non-intrusive manner. Reducing the vibration is important because it shows that smaller vibration amplitude and frequency will reflect better surface and surface quality [1]. The mechanical components that are the most often encountered in rotating machinery are bearings - roller bearings in particular - and gears. In addition, these components are generally the most loaded and therefore subject to early damage in the life of the machine [2]. Vibration-based damage detection for rotating machinery (RM) has been repeatedly applied with success to a variety of machinery elements such as roller bearings and gears.

2.1.1. Spectral Analysis
The vibration signature character in the frequency domain is most prominent. That is why many control methods are focused on the vibration signature's frequency domain characteristics, the continuum. The most successful spectral analysis is applied to the low and intermediate frequency range. The strategy is to extract the signature from a single gear or bearing from the total vibration measured on the machine casing and to monitor the characteristic defect frequency amplitudes. The basic assumption; that a growing defect implies increasing amplitudes at the defect frequencies. Some defect indicators, like the defect severity index, focus on the difference in amplitude at the defect frequency and the amplitude of the background. Other alternative methods focus on the side bands and attempt to build indicators that measure the relative amplitudes of the side bands [3].

2.1.2. Gear Fault
The vibrations of a gear are mainly produced by the shock between the teeth of the two wheels. Gear fault is simulated with filled between teeth. The vibration monitored on a faulty gear generally exhibits a significant level of vibration at the GMF tooth meshing frequency (i.e. the number of teeth on a gear multiplied by its rotational speed) and its harmonics, the distance of which is equal to each wheel's rotational speed [4]. Gear faults can be generally classified into two major categories: distributed faults and local faults. Distributed faults are those faults that results from poor gear mounting, or manufacturing inaccuracies such as eccentricities, varying gear tooth spacing, etc. Meanwhile, local faults are those caused by localizing defects that can occur in gear teeth such as wear of the tooth surface, cracks in gear teeth, and loss of part of the tooth due to breakage or loss of the entire teeth [5].

2.1.3. Correlation between Roughness and Vibration Amplitude
The evaluation of the vibration signals observed during grinding wheel wear in an attempt to determine the tool life. His study determines the average roughness of the work piece increases with the material removed and thus the grinding wheel wear. This in turn results in higher vibration amplitude seen on the tailstock. It concludes by claiming the claimed tool life can be improved with a better signal conditioning algorithm [6]. All gear operations involve some form of sliding contact between the mating gear surfaces. This sliding contact can produce random vibrations from the asperity contacts between the gears, the nature of which is dependent on a number of factors, such as the speed and load, the lubrication conditions and the micro-geometry of the surfaces. Changes in surface roughness would no doubt affect the overall vibration (e.g., rms) level and its frequency characteristics, but it would be very difficult to distinguish surface roughness from other effects [7].
3. Methodology
The aim of this section is to provide the reader about the method that has been done in this paper. The experiments are conducted for after every 100 hours of grinding process. After the grinding process, collection of data will be done; vibration data & roughness measurement data. The correlation data between surface roughness and vibration amplitude has been done using statistical tool which is Minitab19.

3.1. Flowchart

![Flowchart Image]

**Figure 1.** Process Flow

3.2. Gear Specification
Power transmission using bevel gear mechanism can be described as in figure 2. The gear ratio helps to determine the output and input of the speed as well as the torque and power. The gear ratio can be calculated using equation (1). It is vital to determine the gear ratio respect to the individual gear and pinion rotating speed to determine gear mesh frequency in order to locate the appropriate frequency band as given in equation (2).

| Table 1. Gear Specification |
|----------------------------|
| Number of teeth on driven gear | 36   |
| Number of teeth on driver gear  | 11   |
| Gear Ratio                       | 3.27 |
GR = Gear Ratio
T1 = Number of teeth on driven gear
T2 = Number of teeth on driver gear

\[ G.R = \frac{T2}{T1} \]  \hspace{1cm} (1)

\[ G.M.F = \frac{T \cdot N}{60} \]  \hspace{1cm} (2)

GMF = Gear Mesh Frequency (Hz)
T = Number of Gear Teeth
N = Shaft Speed (rpm)

The numbers of gear teeth are 36 and the RPM are 10805. The RPM measured from output gear.

3.3. LMS Data Acquisition
LMS Data acquisition system with 8 channels inputs was used to measure the vibration amplitude of angle grinder. The spectral test lab software was used to filter the data obtained and processed from time domain to frequency domain technique. The procedures such as channel setup, calibration and scope setting were carried out in advance to make sure all data collected are accurate. The detailed scope settings are tabulated below.

| Scope Settings  | 8192.00 Hz     | 8192 | 1.0 Hz |
|-----------------|----------------|------|--------|
| Bandwidth       |                |      |        |
| Spectral Lines  |                |      |        |
| Resolution      |                |      |        |

After the setup has been done, the accelerometer then was properly attached to the bearing on the angle grinder to collect the vibration data.
3.4. Roughness Measurement using Keyence Laser Confocal Microscope

For the surface roughness measurement, two tooth surfaces of the driving gear labelled as marked tooth and adjacent tooth is measured before and after each cycle. Measurement of surface roughness is conducted using the Keyence Laser Microscope. The profile surface features can be seen with details such as the peaks and valleys by using the magnifying lens (20x). These peaks and details created by the grinding process can be seen clearly along the axial direction of gears. This instrument is calibrated before surface roughness of the tested tooth is taken. The calibration is performed to ensure that high precision of surface roughness measurement is maintained. The processes start with optical view followed by laser view.

![Image of Optical View](Figure 4. Optical View for Image Observation)

The average surface roughness (Ra) is used to observe changes in the tooth surface roughness.

![Image of Process of Roughness Measurement](Figure 5. Process of Roughness Measurement)

![Image of Multi-line Settings](Figure 6. Multi-line Settings)
Table 3. Roughness Setting

| Resolution   | 1024x768 |
|--------------|----------|
| Perimeter Lines | 15 lines |
| Interval     | 10 pixels |

4. Result and discussion
In this section, the results are presented, and the behavioural analysis is explained in detail.

4.1. Vibration Data
The frequency of vibration data obtained through the collection of data from LMS. The measurement system is set with chosen frequency which is 6483 Hz. The vibration measurements show that the amplitude steadily increasing after every cycle run. The comparisons between the values of vibration data illustrate that amplitude trend increasing after each cycle run.

Table 4. Vibration Data

| Operating Hour(s) | Amplitude Data |
|-------------------|----------------|
| 0 (baseline)      | 0.20           |
| 100               | 0.44           |
| 200               | 0.62           |
| 300               | 0.86           |
| 400               | 0.90           |
| 500               | 1.00           |

Figure 7. Vibration Amplitude Original

Figure 8. Vibration Amplitude 100 Hours
From these results, the vibration amplitude showed an increasing trend due to gear tooth wear that lead to backlash of gear.

4.2. Surface Roughness Data

The surface roughness measurements, which are obtained through laser microscope of bevel gear in the radial direction, facilitate detailed observations of features of contact surfaces such as the peaks. There two teeth of gear that has been measured and labelled marked tooth and adjacent tooth. The surface roughness measurements show that the tooth surface roughness is changed after every cycle run. The comparisons between the values of surface roughness illustrate that the peak values of surface roughness deteriorate after each cycle run. The peaks decrease from 7.339 to 2.6804 μm for marked tooth while for adjacent tooth, the peak decreases from 6.404 to 3.5422 μm. The surface roughness of gear tooth (Ra) has a steady trend of decrease, as figure 10 and figure 11 shows.

| MARKED TOOTH | 300 HOURS | 400 HOURS |
|--------------|-----------|-----------|
| Total profile | ![Graph](image1.png) | ![Graph](image2.png) |
| Roughness/Primary/Waveless profile | ![Graph](image3.png) | ![Graph](image4.png) |

Table 5. Profile of Roughness
**Figure 10.** Surface Roughness of Marked Tooth after 500 Hours

**Figure 11.** Surface Roughness of Adjacent Tooth after 500 Hours
The tooth surface becomes smoother after a certain number of testing cycles, as shown and explained in the surface roughness results. These results in a good agreement with research found [8].

4.3. Trend Analysis
From results, it shows that surface roughness analysis trend for marked and adjacent tooth are steadily declining after 500 hours of running meanwhile the amplitude of vibration trend are continuing increase after 500 hours of cycle.

**Figure 12.** Trend Analysis for Marked Tooth

**Figure 13.** Trend Analysis for Extended Tooth
Figure 14 and figure 15 show the correlation between gear surface roughness and vibration amplitude after 500 hours of cycle.

From these results, it shows that surface roughness of tooth gear and vibration amplitude correlate with each other by 93.7% for marked tooth and 86.5% for adjacent tooth.

5. Conclusion
Based on the results obtained and presented in the previous chapters the following conclusions can be drawn. The comparison of the surface roughness measurements for both marked and adjacent tooth before and after the test runs shows that a steady trend of decrease. The frequency of vibration data obtained through the collection of data from LMS show that the values of vibration data illustrate that amplitude trend increasing after each cycle run. For 500 hours measurement, the correlation of surface roughness of gear teeth with the amplitude of vibration is 93.7% for marked tooth.
and 86.5% for adjacent tooth, this indicates the strongest possible agreement that when surface roughness of the gear teeth decreasing, the vibration amplitude is higher.

6. References
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