AN OPTICAL METHOD FOR CHATTER AND FORM ERROR DETECTION IN GRINDING

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Introduction

Vibration is an inherent part of the machining processes. Any movement between the tool and work-piece during machining, however, may produce rough and unsightly marks on the parts. If excessive vibration is involved, it will cause dimensional errors on the finished part that results in the rejection of the product. In addition, vibration may reduce tool life, not to mention tool breakage or damage to the machine if the vibration is allowed to grow uncontrolled. Thus, elimination or reduction of machining vibration is a desirable but elusive goal in manufacturing. This requires an early detection of vibration so that a corrective action can be taken in time to remedy the problem.

To detect vibration in a production environment, noise and vibration sensors are used for monitoring the cutting process, however, it is difficult to relate the output of these sensors to the surface conditions and the dimensional accuracy of the part. Often, one needs not only to monitor the process but also the end product as well. In the grinding process for example, the easiest way for process monitoring is by visual inspection of the finished parts. This is normally carried out by experienced operators who are frequently biased and qualitative. For accurate measurement, one needs to resort to the conventional stylus instrument for checking the suspected part. This instrument, however, because of its contact nature, only operates in a clean room and cannot be adapted for high speed on-line inspection.

There is a need for a sensor to measure the surface quality of the part in the manufacturing, especially in grinding which is one of the most common finishing processes in production industries. Because of the non-contact and fast speed advantage, various optical methods were developed for the measurement of surface roughness in a production environment[1]. However they are limited to the measurement of short surface wavelengths[2]. Other sensors were also developed to extend the measurement range[3], nevertheless, their use was limited because of the complexity of the design.

The main objective of this work is to develop a simple optical method to detect chatter marks and form errors on the ground surfaces. These components are mainly periodic; however, they differ in direction, magnitude and frequency. Chatter marks, in general, have larger amplitude and longer surface wavelengths than the machining marks. Form errors, on the other hand have the greatest wavelengths and amplitudes. On cylindrical surfaces such as journal bearings which are the main focus of this work, these errors are termed as "lobbing".

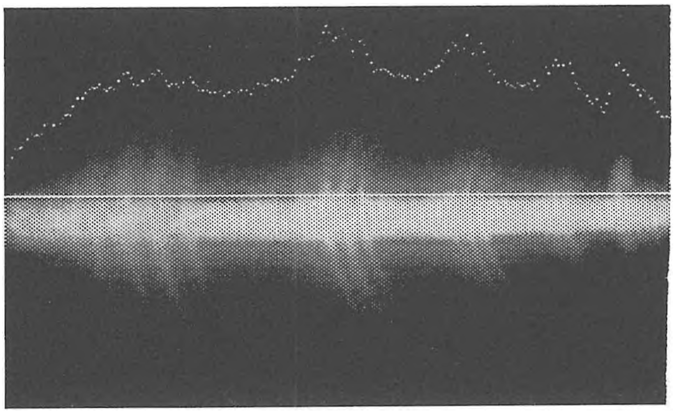

Figure 1

Principle

The proposed method is based on the measurement of the specular reflectance of the light from the ground surface. This reflectance is a function of the local roughness and the slope of the surface of interest. Vibration and chatter marks are the localized rough patches on the surface. As such, they tend to scatter the light in all directions and thereby reduce the reflected light intensity in the specular direction. Machining error or lobbing is the long wavelength component whose slopes modulate the intensity of the reflected beam. Figure 1 shows the light scattering pattern of a ground cam shaft journal with different chatter marks as captured by a CCD camera. These marks are identified as parallel curved lines of different spacings. As the machining marks, chatter marks and lobbing are of different wavelengths, it is possible to identify them in the pattern and subsequently separate them via signal analysis.

Experimental Set-up and Procedure

An optical surface topography sensing device was developed based on the above principle. A schematic diagram of the experimental set-up is shown in Figure 2. This includes a 5 mW diode laser (670 nm wavelength) which was used to illuminate the surface (at a 45 degree incident angle) through a focusing lens. A silicon photo-diode was placed in the specular direction of the reflected light for the measurement of its intensity. An aperture was used to reduce the active area of this photo-diode detector to 0.03 cm^2 for better resolution. A filter was also incorporated in the light path to match the reflected light intensity to the dynamic range of the sensor. The output of the sensor was digitized by an A/D converter and processed by a PC AT.

A number of journal bearings from different camshaft samples was used in the test. Each shaft was held in a fixture which can be rotated at a constant speed of 2 rpm (or 6 mm/s surface speed). As the shaft was rotated, a trace from the photo-diode output was obtained, see Figure 3.

The stylus trace of the sample was also obtained in the same manner using a Talysurf. The shaft in this case was rotated while the pick-up (stylus sensor) was stationary. This would produce a surface roughness profile of the journal. A form measurement was also obtained for the samples by using a Talyrond which would give a trace of the long wavelength components. The stylus traces were then compared to the optical ones to determine the performance of the optical method.

Results and Discussion

The quality of ground sample surfaces varied from good to unacceptable because of excessive chatter or lobbing. The surface roughness of the samples was in the range of 0.2 to 0.4 μm.

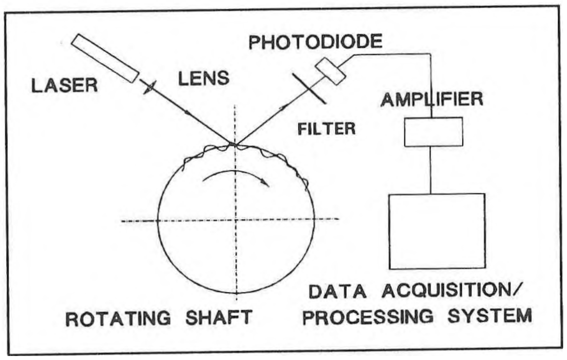

Figure 2

The performance of the optical method was determined by correlating the frequency and amplitude of the optical traces to those of the stylus. To correlate the frequency data, an FFT was performed on both signals and the locations of the major peaks were determined. A typical spatial frequency spectrum of the optical trace is shown in Figure 4. In this figure, one can identify the form error, chatter and vibration marks by their spatial frequencies. These frequencies were confirmed by the results from the Talysurf and Talyrond measurements. A polar plot of the Talyrond trace shown in Figure 5 indicates the presence of predominant chatter marks super-imposed on minor lobbing on the journal surface.

An amplitude (peak to peak) correlation between the optical trace and that of the stylus was also made. This was performed for the surface waviness of a given spatial frequency. Figure 6 shows a correlation curve for the waviness at a spatial frequency of 0.34 c/mm. It can be observed that the optical output increases as the profile amplitude increases, however, the relationship is not linear. This behaviour is likely governed by the relationship between the surface reflectance and roughness. A similar trend was also observed in the correlation at other spatial frequencies.

For a given grinding operation, it is possible to obtain a similar amplitude calibration curve for the part. This calibration curve can be used to determine the rejection threshold in the parts inspection process. For the present set-up, the proposed system can perform a measurement while the part is rotating at a speed of at least 400 inch /min.

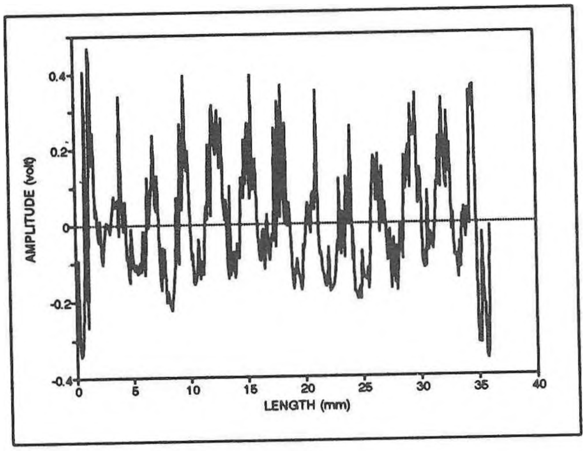

Figure 3

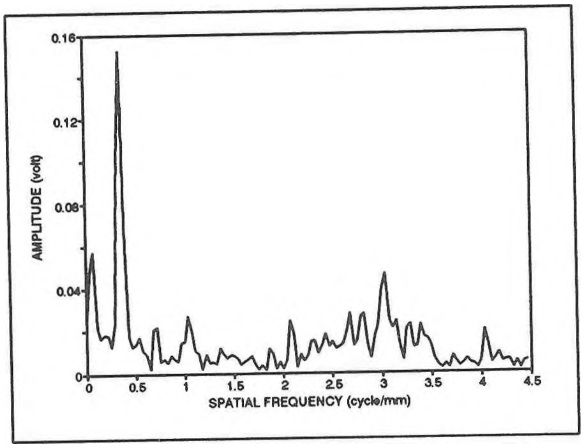

Figure 4

Conclusions

An optical technique for detecting chatter marks and vibration undulation in surface grinding was developed based on the measurement of reflected light intensity from the surface. This method provides a useful tool for routine comparative inspection in production. This method also allows us to determine accurately the wavelength and amplitude of the surface waviness in the machine parts. From this information, one can infer the condition of the tool or machines so that corrective action can be taken at a proper time. With the implementation of an analog circuitry, this method can provide a high speed measurement where the inspecting part is rotating at a high speed. This will enhance the on-line measurement capability of the method. Furthermore, as the method is simple to design and operate, it offers a fairly attractive means for monitoring the grinding process in production or manufacturing industries.

References

[1] Brodmann, R. and Thurn, G., 1986," Roughness Measurement of Ground, Turned and Shot-peened Surfaces by the Light Scattering Method," *Wear*, Vol. 109, pp. 1-13.

[2] Vorburger, T. V., and Teague, E. C., 1981,"Optical Techniques for On-line Measurement of Surface Topography", *Precision Engineering*, Vol. 3, No. 2, pp. 61-83.

[3] Sakai, I., and Sawabe, M., 1982, "A Method for Surface Roughness Measurement by means of Light Reflectance", *Bulletin of Japan Society of Precision Engineers*, Vol. 16, No. 2, pp. 123-124.

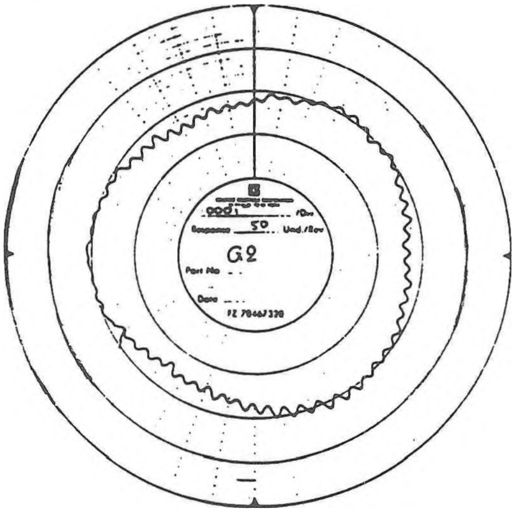

Figure 5

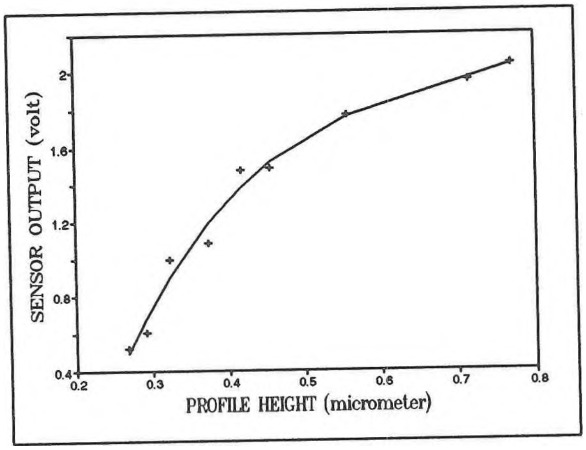

Figure 6