Detection of Defects on the Surface of a Cam Shaft Using Laser Scattering Method

S Dejima¹, T Miyoshi¹, Y Takaya¹ and Y Maeno²

¹ Dept. of Mechanical Engineering and Systems, Osaka University, 2-1 Yamada-oka, Suita, Osaka 565-0871, Japan
² Gunma Main Plant, Fuji Heavy Industries Ltd., 1-1, Subaru-cho, Ohta, Gunma 373-8555, Japan

E-mail: dejima@optim.mech.eng.osaka-u.ac.jp

Abstract. This paper describes a new system to detect defects on the cam shafts of automobiles. The theory, based on laser scattering, is studied first, and then its feasibility is confirmed through basic experiments and simulations. Next, an inspection system is designed and built to verify the effectiveness of the method. The line laser, employed as a light source, illuminates the cam surface and its grey-scale image appears on a CCD as a white line, on which the missing part can be detected when there is a defect. The experimental results show that there is a big correlation between the size of the defect and the missing width. By scanning the laser over the entire surface of the cam shaft, the size and the shape of the defect was measured.

1. Introduction

The need for reliability and high performance in automobiles is increasing all the time, while production costs need to decrease. This results in great demand for the quality and accuracy of components. One of the most important components in the internal engine is the cam shaft, which opens and closes the intake and exhaust valves. Since defects on the cam surface can lead to excess noise and cause breakdown, inspection is absolutely imperative. Inspections have conventionally been carried out by skilled workers, who detect the defects with their eyes. Such inspections, however, produce false results, oversight, and are time-consuming. Therefore an automatic inspection system is required throughout the modern industrial process.

The objective of this study is to develop an inspection system to detect defects on cam shafts. We focused attention on the difference between the texture of a normal surface and that of the defect. The characteristics of the laser intensity, which was reflected on both cam surfaces with and without defects, are carefully examined. An inspection system based on the laser scattering method is fabricated in order to confirm the feasibility of the method.

2. Theory

The texture of a surface affects the scattering pattern when a metallic surface is illuminated. The surface is perceived as changing from smooth or mirror-like to rough or diffused when the roughness of the surface increases [1, 2]. Beckmann showed a novel model of the scattering, derived from the
general Kirchhoff solution [3]. Figure 1 shows the two dimensional geometry model considered in this paper ($\theta_1 = 0$).

The power of the scattered light is weaker than that of the reflected light. The intensity ratio $\rho$ at a distant point for the incident angle $\theta_1$ and the reflection angle $\theta_2$ is calculated and expressed as:

$$\rho(\theta_1, \theta_2) = \frac{\rho_0^2 + \sqrt{\pi F_2 \frac{L}{2L} \sum_{m=1}^{\infty} \frac{g^m}{m! \sqrt{m}}} \exp\left(-\frac{v_x^2 T^2}{4m}\right) \exp(-g)}{\left(1 + \cos(\theta_1 + \theta_2)\right)^2}$$

where $L$ is the surface length, measured in the x direction, the roughness is evaluated in $R_q$.

$$\rho_0 = \frac{\sin(v_x L)}{v_x L}$$

$$F_2(\theta_1, \theta_2) = \sec(\theta_1) \frac{\cos(\theta_1 + \theta_2)}{\cos(\theta_1) + \cos(\theta_2)}$$

$$g = \frac{2\pi R_q}{\lambda} \left(\cos(\theta_1) + \cos(\theta_2)\right)^2$$

$$v_x = \frac{2\pi}{\lambda} \left(\sin(\theta_1) - \sin(\theta_2)\right)$$

$T$ is the correlation distance for which autocorrelation coefficient $C(t)$ has decreased to $e^{-1}$. The value is equal to the average value of the spacing of adjacent crests on the cam surface. The sensor system presented in this paper scans the laser over the cam surface and examines the specular intensity to detect the defect. In such cases, $\theta_2$ is the same angle as $\theta_1$. Also a set of $\theta_1$ and $\theta_2$ varies in accordance with the inclination of the cam surface during the inspection.

The roughness of the cam surface is measured by a stylus instrument (Surfcom, Tokyo Seimitu). The measured value of $T$ was 1 $\mu$m. Figure 2 shows the results from a simulation of the intensity ratio $\rho$ calculated from equation (1). As can be seen in the figure, from a certain angle, the intensity ratio decreases as the roughness increases. When $R_q$ is less than 0.1 $\mu$m, the ratio $\rho$ varies accordingly. On the other hand, the ratio is nearly equal to zero when $R_q$ is larger than 0.1 $\mu$m. Although the intensity ratio decreases with respect to the incident angle, significant change cannot be seen.

Using a line laser whose length is longer than the width of the defect, the reflection intensity from the defect is weaker than that from the normal surface. The difference is applicable to defect detection. To confirm the validity of this principle, the relative intensity of $\rho$ upon the normal surface to $\rho$ upon the defect surface is calculated. The roughness $R_q$ of the normal surface and the defect surface on the cam is measured by the stylus instrument, and it turns out to be 0.072 $\mu$m on the normal surface and 0.5 $\mu$m on the defect surface. The relative intensity of $\rho$ on $R_q=0.072$ to $\rho$ on $R_q=0.5$ is shown in figure 3. The result shows that the relative intensity is always greater than 1.5, so that the intensity reflected from the normal surface is higher than that from the defective surface. Therefore the defect can be detected when the reflected intensity can be analyzed.
3. Inspection system

Figure 4 shows the schematic of the measurement system. A line laser from a LD unit, $\lambda=650$nm, which is used as a light source, is projected onto the cam surface after being bent by a mirror. To scan the laser over the entire circumference of the cam continuously, the shaft can be rotated around the axis with a rotation stage. The cam shaft consists of six cams, which are inspected one by one. The shaft is mounted on the X stage and the cam to be inspected is moved under the sensor. The laser is reflected from the cam according to the inclination of the surface. The mirror changes the direction of the reflected laser so that the beam can propagate through the lens unit. The mirror is mounted on the rotation stage and the inclination of the half mirror can be properly controlled. The lens unit is designed so that the beam focuses on a CCD. The CCD located on the focus of the lens unit captures the cam surface image. The position of the CCD is also controlled with automatic stages in the y and z directions in order to be arranged in the proper position. Those optical alignments were determined from the viewpoints of geometric optics, so that the entire circumference of the cam can be detected by any rotation of the cam.

The image is sent to a PC which carries out the image processing through the CCD module driver. If there is no defect on the surface, we can observe one white line on the CCD image. On the other hand, if there is a defect, a part of the line must be missing in proportion to the defect size and position. As a result, measurement of the size and the missing position gives us the respective size and position of the defect.
4. Experimental results

Figure 5 (a) and (b) show examples of the CCD image of a normal and a defective cam, respectively. A white line can be seen because the line laser was employed for illumination. We can easily recognize the missing part on the white line when there is a defect on the cam. The relation between the defect size and the width of the missing part is investigated. The calibrated width of the missing part is drawn in figure 6 where three kinds of artificially formed defects are measured. It is confirmed that the width of the missing part increases as the size of the defect increases. Figure 7 shows the result from measuring the defective cam shaft. As the cam is rotated around the axis, the inspection was carried out. The shape of the defect is obtained from the rotation angle, the width and the position of the missing part. The defect is also measured with a stylus instrument for comparison. The result agrees with the one from the stylus instrument.

![Image of a normal cam.](image1)

![Image of a defective cam.](image2)

Figure 5. Gray-image of a cam shaft.

![Figure 6. The width of the missing part on the white line.](image3)

![Figure 7. The detected defect.](image4)

5. Conclusion

We propose a defect inspection system based on the laser scattering method. From a theoretical point of view, the feasibility of the method is studied. The difference of texture clearly identifies defects for any inclination of the cam. The inspection system is built to verify the effectiveness of the method. The system is capable of detecting defects over the entire circumference as the optical arrangement changes according to the cam shape. Not merely the defect itself, but also the size and the position can be detected. In-situ inspection is our future work.

References

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