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LIQUID LEAK DETECTION USING LASER TRIANGULATION

Keywords

Liquid leak, non-contact distance measurement, laser triangulation.

Absctract

For liquid leak detection in machines and industry systems the non-contact laser triangulation can be applied successfully. The refraction of laser ray emitted by sensor head while entering the liquid is used. Experimental tests were carried out for machine oil. Obtained results confirm the possibility to detect oil layers with high accuracy in micrometers. In the paper the idea of a measurement system with opposite laser sensors for oil leak detection on piston rods and shafts was presented.

Introduction

The increasing number of inspection and quality control systems in industry need non-contact techniques for measurement when materials or parts are elastic, soft, liquid, very hot or in motion. Liquid leak detection in machines, industry systems and hazardous liquid pipelines is an important problem [1, 3]. Power units, turbines, tanks, high power hydraulic actuators need permanent monitoring to prevent failures and to protect environment. Leak detectors are applied in automotive industry in tests and quality control of shock absorbers.

There are numerous methods to monitor and detect liquid leak based on: electrical conductivity or resistance, mass balance, flow, pressure, electrochemical sensing or a selective chemical sensing, optical [2], ultrasonic [5] and acoustic.

Laser based triangulation sensors enable distance measurement with a high accuracy and can be used for the detection of liquid layers presence on the object's surface. This technique ensures a high sampling rate, which is a crucial feature for carrying out the measurement on moving objects.

1. Measuring principle

This measurement method employs an optical triangulation principle. In laser triangulation a laser light source, imaging optics and a photo detector are used. The laser light emitter is used to generate a beam of light, which is projected onto the object surface (Fig. 1). The lens of CCD mini camera mounted in the measurement head focuses the spot of reflected laser beam onto the CCD sensor. Electronic circuit generates a signal, the voltage value of which is proportional to the image spot position on the sensor. As the object surface position changes, the image spot shifts due to the parallax. Using commercially available, compact laser triangulation sensor, we can measure distances with high accuracy. A voltage signal from the sensor is calculated as to achieve a distance value.

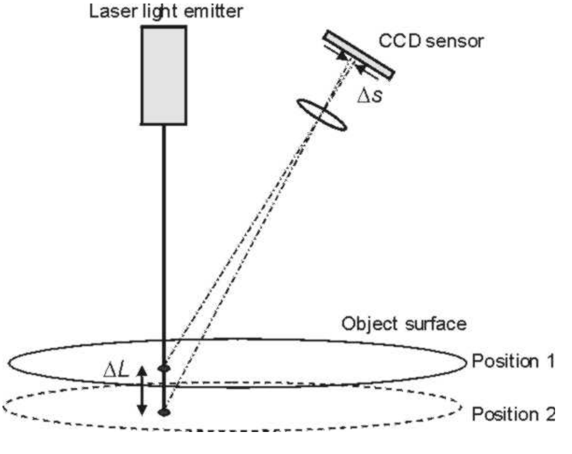

Fig. 1. Principle of a laser triangulation

The laser beam is projected onto the object surface through the liquid. The laser ray is refracted on the boundary between two media: air and liquid (Fig. 2). A refraction angle depends on the refractive index of the liquid related to optical density. Due to the refraction, the image of laser spot is visible for the sensor on the smaller depth. The real distance *d* between object surface and liquid surface is indicated as apparent distance *d'*.

For situation shown in Fig. 2, using known Snell's law of refraction, where refractive index for air medium equals 1 we have:

$$\sin\alpha = n \cdot \sin\beta \tag{1}$$

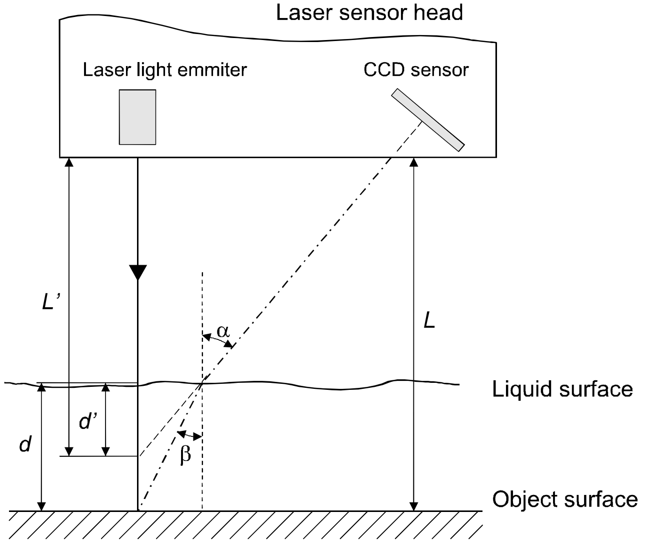

Fig. 2. Laser triangulation based distance measurement through liquid

From the geometrics shown in Fig. 2:

$$L = L' - d' + d \tag{2}$$

and

$$d' \cdot tg\alpha = d \cdot tg\beta \tag{3}$$

where:

L – distance measured by sensor,
L' – mid distance of laser sensor.
d – thickness of liquid layer,
β – mid-angle of sensor's optics,
α – refractive angle in liquid,
n – refractive index of liquid to air medium.

From equations we derive:

$$L = L' + d\left(1 - \frac{tg\beta}{tg\alpha}\right) \tag{4}$$

If the distance *L'* is fixed and known we can calculate layer thickness *d*:

$$d = \frac{L - L'}{1 - \frac{tg\beta}{tg\alpha}} \tag{5}$$

For LK-031 Keyence sensor [4] used in experiments we have: mid-angle $\alpha = 40^{o}$ and mid-distance *L'*=30 mm. For red light of 760 nm wave length the refractive index of oil approx. n=1.45. From (5) and (1) we have:

$$0{,}41d = L - 30{,}00 \tag{6}$$

If "zero adjusting" on the diffuse object surface as the "zero base" is used we have:

$$0{,}41d = \Delta L \tag{7}$$

where ΔL is the value of output signal.

2. Experimental results

The experimental set-up structure is shown in Fig. 3. The LK-031 laser sensor with controller was used [4] to measure the distance to object.

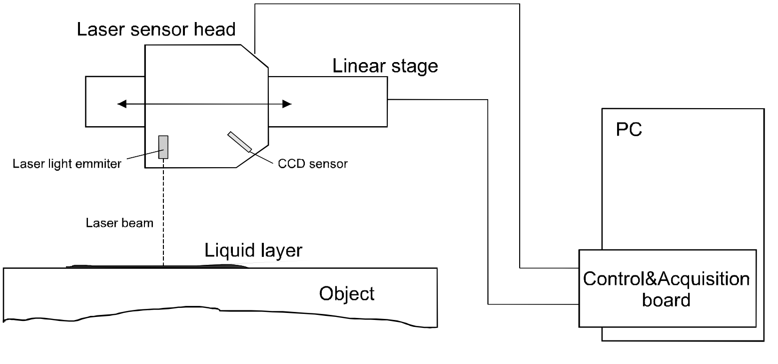

Fig. 3. Experimental set-up for scanning the liquid layer on the object

Fig. 4 presents the profiles of liquid layers on the object obtained during scanning. Original signals are noisy because of the high reflection of surface. Using filtering and processing, we can obtain a profile of liquid layer and precisely measure the layer's thickness. The LK-031 controller gives signal 1 mV for every 1 μm in air. The height in [μm] scale after converting from sensor signal in [mV] is presented on vertical axis. The profile's heights (profile B) were recalculated based on equation (7).

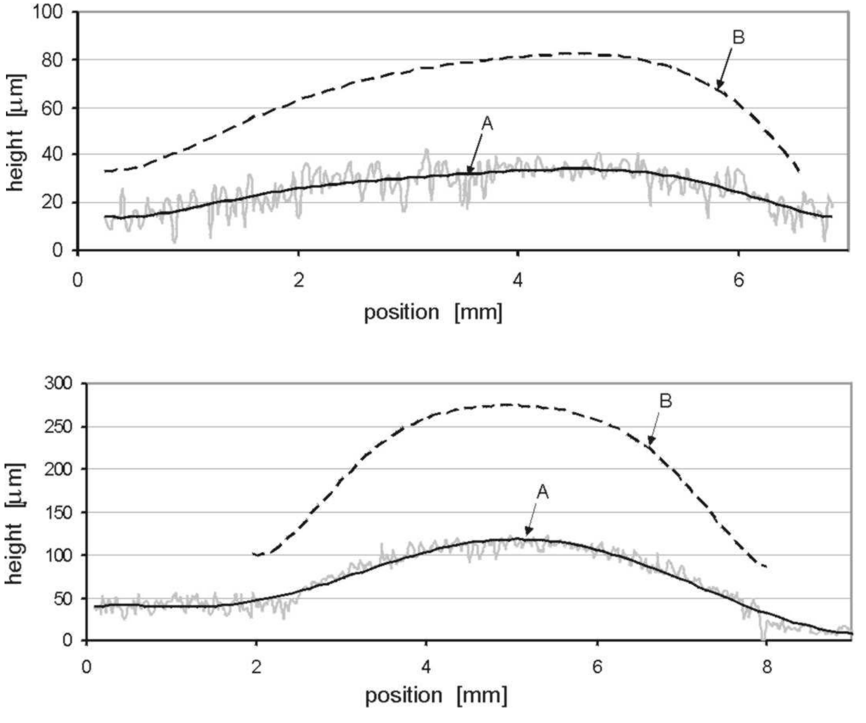

Fig. 4. Experimentally obtained oil layer profiles: A-apparent profile after filtering and processing, B-recalculated profile

The scanning process was presented to show the efficiency of laser triangulation method. For inspection in industry, as well as for quality tests, and effective liquid leak detection, the in-point measurement is sufficient. The scanning system is complicated and too time-consuming where the short measurement time is critical for high dynamic processes.

For high accuracy detection of liquid leak on an object in motion, like shafts or piston rods, two synchronized laser sensors can be used. The structure of the liquid leak detection system with in-point measurement is presented in

Fig. 5. Two oppositely mounted laser sensors measure distance between points on the object surface. The measurement is highly insensitive of object displacement. The advantage of using differential signal enables high accuracy of measurement, approx. 1 μm.

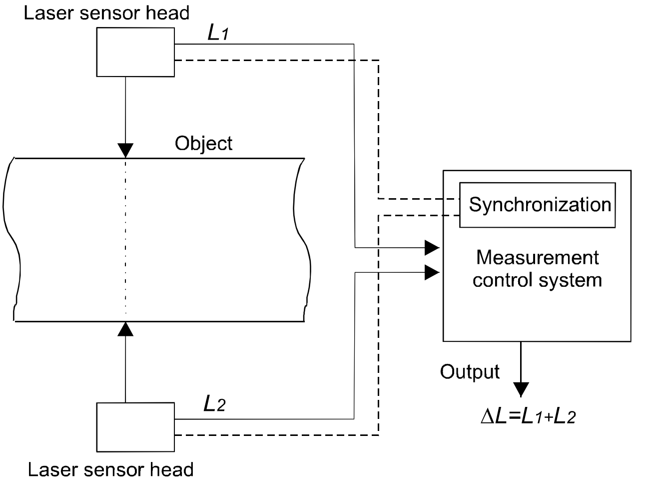

Fig. 5. Measurement system with opposite sensors

Conclusions

The non-contact laser triangulation can be used for effective liquid leak detection ensuring a high accuracy in micrometers. Experiments have shown the possibility to detect thin oil layers on a high reflective surface like piston rods. For standard industry applications, the basic laser triangulation sensor with controller can be used. When the high accuracy liquid leak detecting is needed, the more advanced measurement system with opposite Keyence sensors and two-channel controller can be applied [4]. Such a system can be used for tests and quality control of shock absorbers in manufacturing. The laser triangulation based measurement system can be used for liquid level detection and precision measurement in numerous applications [6].

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Reviewer:
Dariusz BOROŃSKI

Wykrywanie wycieków cieczy z wykorzystaniem triangulacji laserowej

Słowa kluczowe

Wyciek cieczy, bezkontaktowy pomiar odległości, triangulacja laserowa.

Streszczenie

Do wykrywania wycieków cieczy w maszynach i systemach przemysłowych może być z powodzeniem zastosowana metoda triangulacji laserowej. Wykorzystywane jest zjawisko załamania światła laserowego wysyłanego przez głowicę sensora przy wnikaniu do cieczy. Testy eksperymentalne zostały przeprowadzone dla oleju maszynowego. Uzyskane wyniki potwierdzają możliwość detekcji warstw oleju z czułością rzędu mikrometrów. Przedstawiona została koncepcja systemu pomiarowego z dwoma sensorami do wykrywania wycieków oleju na tłoczyskach i wałach maszynowych.