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Design and Performance Analysis of Laser Displacement Sensor Based on Position Sensitive Detector (PSD)

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Abstract. By using PSD as sensitive element, and laser diode as emitting element, laser displacement sensor based on triangulation method has been widely used. From the point of view of design, sensor and its performance were studied. Two different sensor configurations were described. Determination of the dimension, sensing resolution and comparison of the two different configurations were presented. The factors affecting the performance of the laser displacement sensor were discussed and two methods, which can eliminate the affection of dark current and environment light, are proposed.

1. Introduction

Laser displacement sensor makes use of laser beam measuring distance, displacement and vibration in a non-contact mode, and PSD (Position Sensitive Detector) is one of its important components. PSD is one of the important opto-electro semi-conductor components developed for real time measurement of position, displacement, vibration, and etc, it outputs analog signals representing the position of incident light spot on its sensing surface. Using PSD device and LD (laser diode), laser displacement sensor can be built based on laser triangulation method. Compared with CCD device, PSD has the features of high sensitivity, high response and simple detecting circuit, and furthermore it has continuous sensing surface, but because it utilizes analog signal and can only detect the centroid of the incident light energy, it is easily affected by environment stray light, and its output signal can not be further processed like image processing of the digital signal of CCD device. In order to increase the measuring accuracy of PSD device based displacement sensor, structural design and factors affecting measuring accuracy should be studied.

In this paper, issues related to the design of PSD based laser displacement sensor are analyzed, factors affecting measuring accuracy are examined and two methods for eliminating the adverse effects caused by dark current and environment stray light are presented.

2. PSD device and position detection methods

There are two types of PSD device, i.e. linear and area types, or one- and two-dimensional types. The section drawing of linear type PSD is shown in Figure 1. PSD is P-I-N three-layer-structure of Si semiconductor, P-layer is light-sensitive surface, there are two electrodes on its two ends, and the common electrode is connected to reverse voltage. When a light beam is irradiated on light-sensitive surface, lateral electromotive force, will be generated parallel to PN junction. Due to photo effect, current I_0 is generated by incident light. Because of the existence of lateral electromotive force, current is divided into I_1 and I_2 flowing to the two ends on P-layer, $I_0 = I_1 + I_2$. Current distribution is decided by the effective resistors between the position of light spot and the ends. Because resistance on the P-layer is uniformly distributed, so there is the following relationship:

$$\frac{I_1}{I_2} = \frac{L-x}{L+x} \tag{1}$$

$$x = L \cdot \frac{I_2 - I_1}{I_2 + I_1} \tag{2}$$

According to equation (2), the output position signal is only decided by light spot position and has no relationship with light intensity.

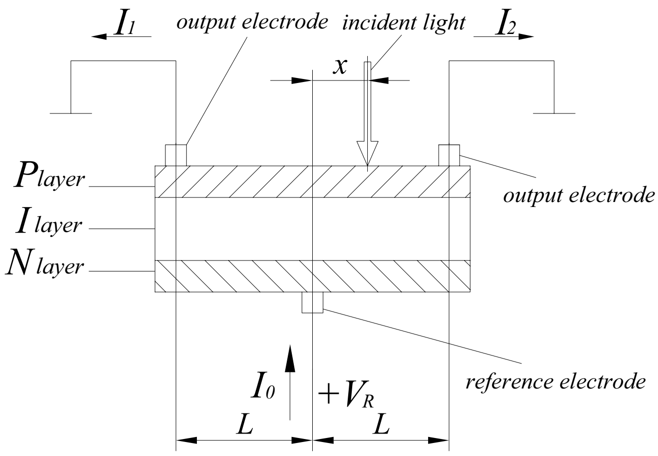

Figure 1. Sectional drawing of linear type PSD.

There two position detection methods, i.e. the amplitude method and the phase method [1]. The amplitude method determines the position of the incident light beam from difference in the amplitude of the dc currents generated by a steady-state light excitation. The phase detection electronics first convert the currents from the PSD to a voltage, which is then further processed to measure the time difference between the zero crossing points of the sinusoidal outputs, and finally converts the time difference to a voltage which is proportional to the phase difference.

3. Dimension determination in structural design and analysis

The configuration or component collocation of PSD based laser displacement sensor has two types, as shown in Figure 2(a) and (b), all of them are based on optical triangulation method. The position of light spot x can be obtained by detection circuit, and according to the light spot position the distance of the object to be measured can be calculated:

$$d = \frac{b \cdot c}{a + x} \tag{3}$$

$$d = \frac{b \cdot (a+c) \cdot \cos\alpha + b^2 \cdot \sin\alpha}{b \cdot \sin\alpha + x} \tag{4}$$

(3) is for the configuration type of Figure 2(a), and (4) for type of Figure 2(b).

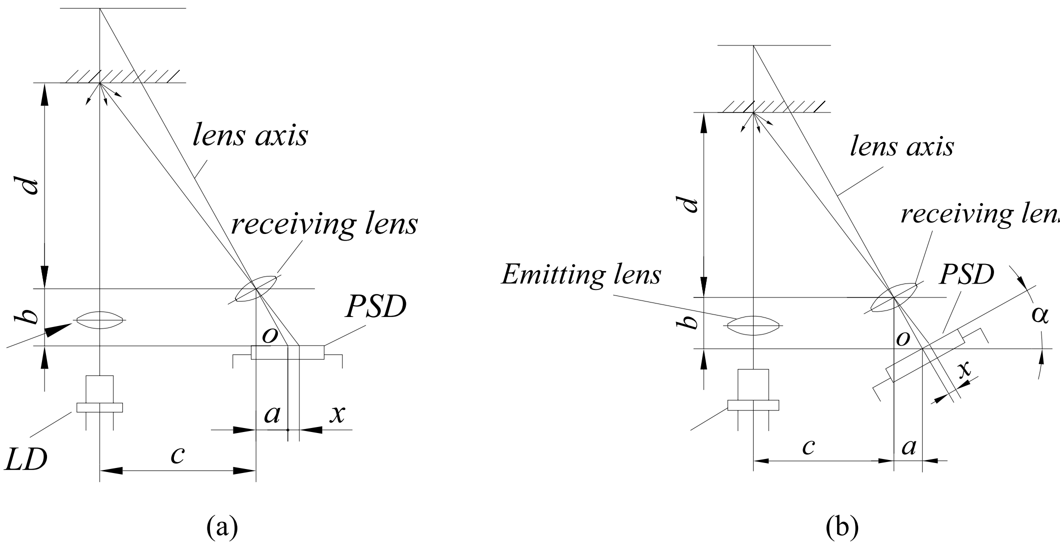

Figure 2. Configurations of PSD based laser displacement sensor.

The resolution of the displacement sensor is determined by the sensitive elements and the configuration of the sensor. PSD has continuous sensitive surface, its detection resolution is determined by noise of outside detection circuit and the light-generated current, generally in the range of sub micrometers. As to the configuration of Figure 2(a) and (b), from (3) and (4), there are:

$$\Delta d = -\frac{d^2}{b \cdot c} \cdot \Delta x \tag{5}$$

$$\Delta d = -\frac{d^2}{b \cdot (a+c) \cdot \cos\alpha - b^2 \cdot \sin\alpha} \cdot \Delta x \tag{6}$$

In design, the resolution of the sensor to be developed can be determined with equation (5) and (6). The following equations can be used in dimension determination for configuration of Figure 2(a):

$$L_1 = \sqrt{a^2 + b^2} \cdot \sin^2\alpha \tag{7}$$

$$L_2 = \sqrt{a^2 + b^2} \cdot \cos^2\alpha \tag{8}$$

$$f = \sqrt{a^2 + b^2} \cdot \sin^2\alpha \cdot \cos^2\alpha \tag{9}$$

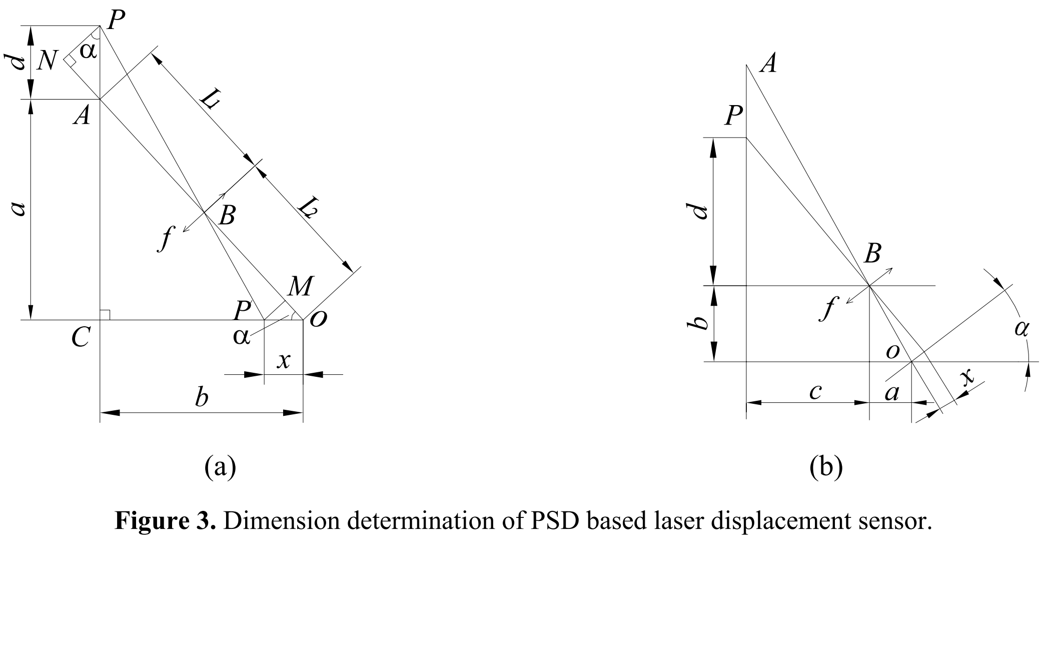

Figure 3. Dimension determination of PSD based laser displacement sensor.

As to the configuration of Figure 2(b), referring to Figure 3(b), the principle of dimension determination is to let the image of reference point A be in the sensitive surface of PSD according to lens imaging equation. It should be noted that in practice, the thickness of lens must be considered and accordingly to adjust the installation position of components.

The sensors of both configurations shown in Figure 2 are easy to be fabricated, and also convenient for component installation and adjustment. Configuration of Figure 2(a) has better light spot imaging quality, and when $\alpha = 45°$ and $L_1 = L_2$, in measuring range the light spots can all image in PSD sensitive surface; As to configuration of Figure 2(b), only the reference point images in PSD sensitive surface, other light spots in the measuring range have images out of PSD sensitive surface, but the reflected light rays are nearly perpendicular to PSD sensitive surface and thus more irradiation energy is received. According to equation (5)(6), the resolution gets worse as the measuring distance increases, but configuration of Figure 2(b) has small influence.

4. Factors affecting measuring accuracy

Factors affecting measuring accuracy consist of factors caused by the sensor itself and the ones caused by outside environment.

The factors caused by the sensor itself include: (1) the aberration of optical system; (2) the size of light spot; (3) the position detection error of PSD device and its resolution; (4) the dark current and environment stray light; (5) the accuracy and noise of PSD detection circuit [2]; (6) temperature drift of electronic circuit and optical system.

The factors caused by outside environment include: (7) tilting of the surface being measured; (8) the unevenness of the surface being measured; (9) the difference of reflective characteristics of the surface being measured.

The aberration of optical system refers only to mono-color aberration, including spherical aberration, coma, image dispersion, etc. All of the aberrations cause the light spot position away from the expected position. As to PSD device, if blurred light spot image is formed within its sensitive surface, the affection of the aberration is the change of the centroid of incident light energy, the shape of light spot on PSD sensitive surface has no much influences.

The size of light spot affects measuring accuracy with the surface to be measured. Generally speaking, large size has deep effect, so thin and energy concentrated light beam is preferred.

The dimension of the sensor case and optical component will change along with temperature, usually, by setting application temperature range to limit the errors caused by temperature.

Taking the following method, most of the effects caused by the factors of the sensor itself can be eliminated.

Microcomputer and A/D converter are used in sensor design, after the sensor is fabricated, the optical system is settled and calibration performed. Surface to be measured is moved by precision stage, the position of surface being measured and the light spot image position x are input to microcomputer and saved in ROM, in real measurement, search and interpolation will be done according to the output of PSD detection circuit.

It should be pointed out that surface characteristics are quite different with different objects, and as a result the reflected light energy is far beyond the same. So according to signal intensity, the output intensity of LD and the amplification of PSD detection circuit should be adjusted. Furthermore, for high precision measurement, requirements on characteristics of surface to be measured should be put forward, in order to assure measurement.

5. Elimination of dark current and environment stray light [3]

When there is no incident light on PSD sensitive surface, the output current at the electrodes are called dark current. Dark current changes with the reverse voltage and temperature. It affects measuring accuracy with environment stray light. When dark current is very small, light-cut off filter can be used to get rid of most of the environment stray light. The following methods can eliminate the affection of both the dark current and environment stray light.

5.1. Modulation detection method

Modulating the output of LD, the signal detected by PSD is also modulated signal, by synchronous detection, low pass filtering, DC signal can be obtained, as shown in figure 4.

Synchronous detection is like multiplier, if $u_{11}=U_{11}\cos(\omega t)$, $e_1=E\cos(\omega t+\Phi)$, there is:

$$u_{12}=u_{11}\cdot e_1=U_{11}\cdot\cos(\omega\cdot t)\cdot E\cdot\cos(\omega\cdot t+\Phi)=\frac{1}{2}U_{11}\cdot E\cdot[\cos\Phi+\cos(2\omega\cdot t+\Phi)] \tag{10}$$

After low pass filtering:

$$u_{13}=\frac{1}{2}U_{11}\cdot E\cdot\cos\Phi \tag{11}$$

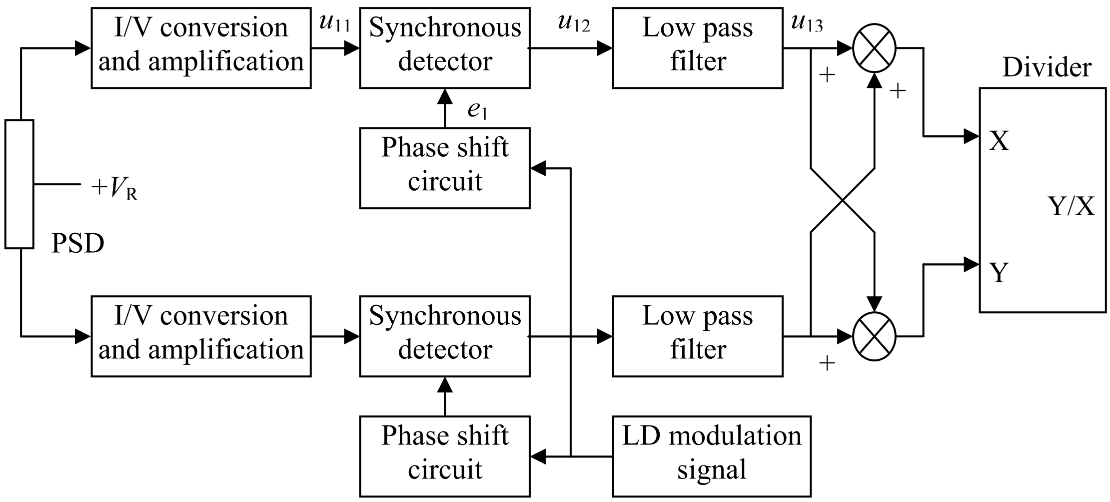

Figure 4. Modulation detection method.

5.2. Sample-hold detection method

Sample-hold devices SH(1)-SH(4) are used in this method and controlled by signal A_1 and A_0 simultaneously with the control of LD. At first, SH(1)-SH(4) are in sample state, after a short period of time for sampling, turn SH(1) and SH(2) into hold state. The inputs of SH(3) and SH(4) are the difference values of PSD outputs corresponding to LD on and LD off respectively, so the influence of

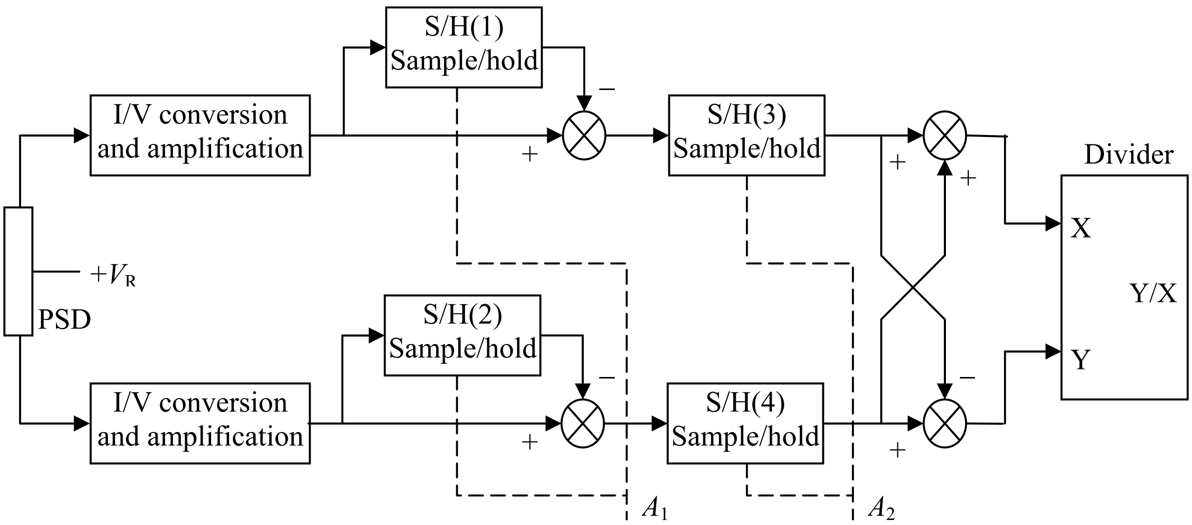

Figure 5. Sample-hold circuit diagram.

dark current and environment light is eliminated. Then after sampling time, turn SH(3) and SH(4) into hold state, and then the output signal is the effective displacement signal.

6. Conclusion

PSD device and its detection method are briefly introduced in this paper; the configurations of PSD based laser displacement senor are explained, sensor structural dimension determination and sensor resolution are analyzed, comparison of the two configurations are given. The factors affecting measuring accuracy are examined and two methods for eliminating of the effects caused by dark current and environment stray light are presented.

Acknowledgments

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