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HIGH PRECISSION OPTICAL POSITION SENSOR FOR ELECTROMAGNETIC FORCE COMPENSATED BALANCES

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Abstract – This paper discusses an optical position sensor which can be used in balances based on the principle of electromagnetic force compensation (short used EFC) for example. Other applications are zero point detection as well as high precision positioning in the range of ± *200 µm*. The position sensor consists of two infrared-LED (IR-LED) which illuminate a single photodiode via an aperture. The aperture is movable and performs a shadowing of the beams, thus shadowing changes due to the position of the aperture. The photodiode detects light from both LED. Both light sources have to be modulated and phase shifted to distinguish them in the photodiode signal. The evaluation of the position of the aperture is done by demodulating the received signal.

A major advantage of this method is that the aperture's operating point is in the centre of the beams. Hence higher sensitivity is achievable and the beams can be focused onto the photodiode. Furthermore standard components are used and thus expensive differential photodiodes are no longer necessary.

Keywords: position sensor, zero point detection, balance with electromagnetic force compensation

1. INTRODUCTION

Balances according to the principle of EFC are commercially used for high-precision mass determination with a resolution in the range of 10 million steps. The deviation of the zero point of the lever of these systems is determined by a position sensor. The zero position has to be kept constant in the range of some nanometers due to the spring constant of the weighing system. Deviations from the zero position can be reflected as an error component to the measuring force. [1], [2]

Commercial position sensors which are used in balances with EFC are mainly operating with one IR-LED and one differential photodiode. An IR-LED (1) illuminates a differential photodiode (3) via a narrow movable rectangular aperture (2), see figure 1. The difference of the two signals of the differential photodiode is directly proportional to the position of the aperture.

A disadvantage of this arrangement is the fabrication of the narrow rectangular aperture and the large resulting blockage of the light. Furthermore this requires an appropriately high current of the LED. Besides this differential photodiodes are comparatively expensive.

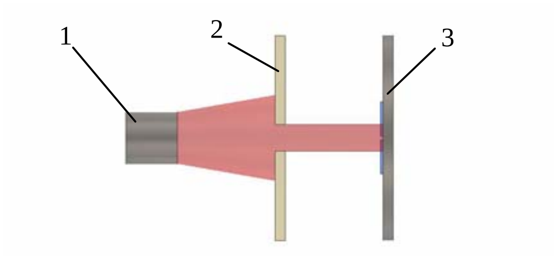

Fig.1. Position sensor with one LED and differential photodiode

2. DUAL-LED POSITION SENSOR

2.1. Setup

The introduced position sensor solves this problem by using two IR-LEDs (1, 2) and one photodiode (3). The width of the movable aperture (4) ideally corresponds to the distance between the two beam focuses in the plane of the aperture. See Fig. 2.

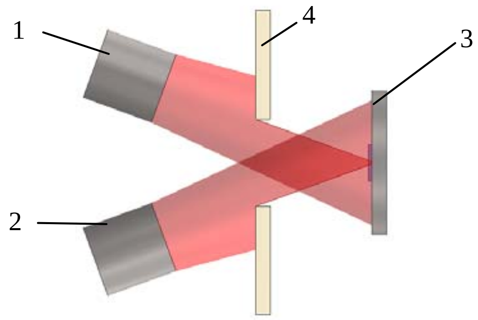

Fig.2. Dual-LED position sensor

The signals of the IR-LEDs are modulated and phase shifted by 180 degrees to distinguish the light components on the photodiode. Influences by extraneous light are suppressed very well by the modulation.

The used LEDs in this setup are OD880F, the photodiode is a BPX65. The LED has its emission peak at $\lambda_p = 880\ nm$ and a narrow beam angle of $\theta = 16°$ [3]. This results in a small illuminated area.

The photodiode has its maximum sensitivity at a wavelength of $\lambda_s = 850\ nm$ [4]. It is very well suited for the combination with the chosen LED.

Both the LEDs and the photodiode have a hermetically sealed metal housing with a glass window (BPX65) or respectively a glass lens (OD880F). This results in a good protection against environmental influences such as humidity.

The angle between the axis of the LEDs and the axes of the photodiode is defined by the diameter of the LED housing and its distance to the photo element (see fig. 3).

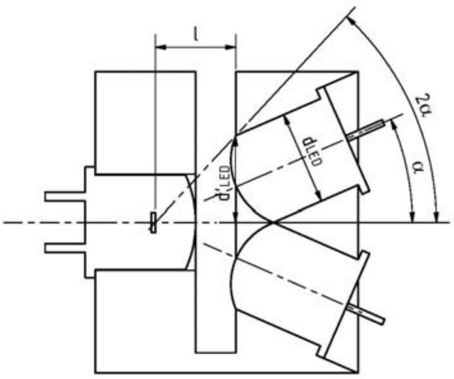

Fig.3. Specific setup of the dual LED position sensor

The angle α is defined via

$$\cos\alpha = \frac{d'_{LED}}{d_{LED}} \tag{1}$$

$$\tan(2\alpha) = \frac{d'_{LED}}{l} \tag{2}$$

Equation (1) and (2) combined results in

$$\frac{\cos\alpha}{\tan(2\alpha)} = \frac{l}{d} \tag{3}$$

This equation is only numerically solvable. In this specific case with $l = 4\ mm$ and $d = 4.7\ mm$, the angle is $\alpha = 23.5°$.

The width of the aperture ideally corresponds to the distance between the two beam focuses in the plane of the aperture. The width of the aperture corresponds to the angle of the LED axis (equation 4).

$$d_{Ap} = 2 \cdot l_{Ap} \cdot \tan\alpha \tag{4}$$

The distance between the aperture and the photo element is called l_{ap}. In this specific case the width of the aperture is approximately $d_{ap} = 3\ mm$.

2.2 Description of Circuit

The circuit is designed to drive the two LEDs with a modulated current. The LEDs are driven by a modulated current signal to which an offset signal is added in order to get a continuous light flux.

The light flux of the two LEDs is combined on the photo sensor of the photodiode causing a photoelectric current. The signal depends on the position of the aperture which covers some parts of both beams. If the aperture is in the center position the photoelectric current is a constant signal, otherwise the current is modulated.

The photoelectric current is converted into a voltage and filtered with a high pass filter to eliminate offsets (resulting by extraneous light).

The demodulation of the signal is done by the circuit AD630 from Analog Devices [5], which is an analog modulator/demodulator. The reference signal for the demodulation is the high pass filtered current for one of the two LED. The current is converted into a voltage by the series resistor of the LED. This reference signal should not be taken from the modulation signal due to phase shift of the voltage to current converters of the LED.

The demodulated signal is filtered by a low pass filter to get a constant signal, which corresponds to the position of the aperture.

The block diagram of the circuit is shown in fig. 4

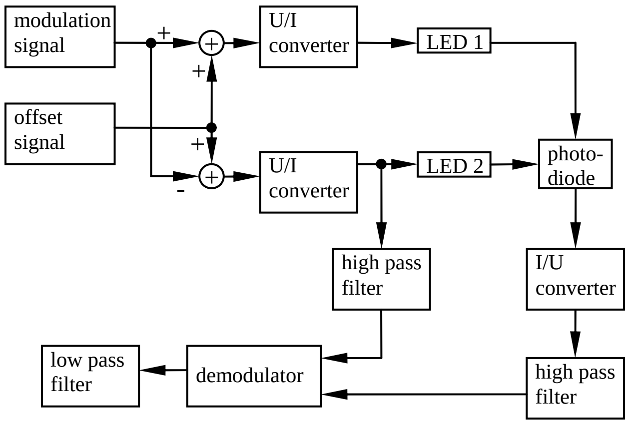

Fig.4. Block diagram of the dual LED position sensor circuit

3. SIMULATION

The simulation for the dual LED position sensor with its circuit described above was done in MATLAB Simulink.

3.1. Characteristics of LED

A LED has a nonlinear current to light flux transfer function. The transfer function is measured by applying a current to both LEDs and measuring the photo current of the photodiode. Due to the linear behavior of the photodiode the photo current is multiplied with the spectral sensitivity to get the light flux. The best fit is a fifth degree polynomial (see fig 5.). This nonlinear behavior causes higher modes in the modulated signal of light.

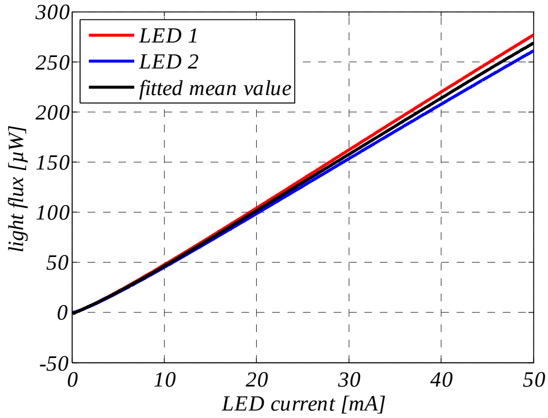

Fig.5. Transfer function of LED

The intensity distribution of the LED is not uniform. Thus the relation of the apertures position and illumination of the photodiode depends on the position.

3.2. Simulation

The simulation includes the influences of the LED's current to light characteristics as well as the effects caused by the non-uniform beam profile. Figure 6 displays the simulated curve (blue) and its deviation from the linear fit. The sensitivity of the curve is $E_{sim}= 1.25V/mm$.

The deviation (red curve) is caused only by the beam profile of the LEDs.

Due to the demodulation and the filtering of the signal, the nonlinear current to light characteristic of the LED has no influence on the signal.

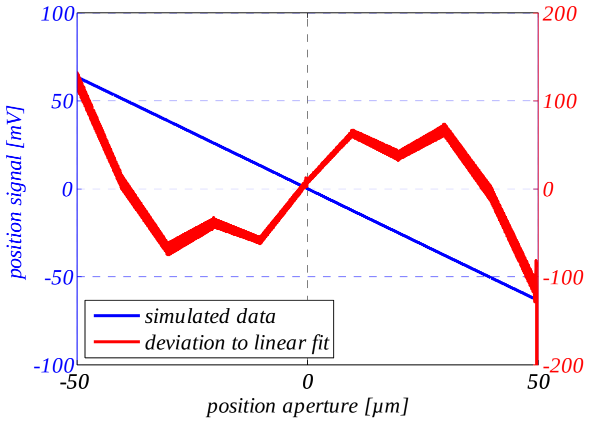

Fig.6. Simulation of dual LED position sensor

4. MEASUREMENT RESULTS

4.1. Characteristic curve

The characteristic curve of the dual LED position sensor was measured with a high precision positioning system with a positioning resolution of $A_{pos}=1\ nm$ and a maximum displacement of $\Delta x=\pm 40\ \mu m$. The displacement was measured with an interferometer, thus it is traceable to the length standard.

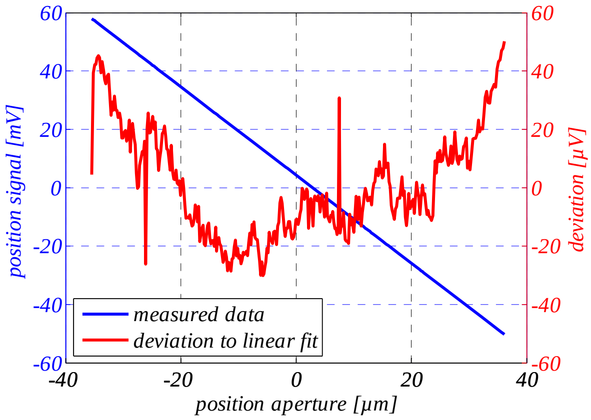

Fig.7. Characteristic curve of dual LED position sensor

Figure 7 displays the characteristic curve of a dual LED position sensor.

The blue curve represents the measured position signal of the position sensor in volts. The curve was fitted with a first degree polynomial to obtain the sensitivity. The red curve shows the deviation of the measured data from the fitted curve. The nonlinearity of the position sensor is caused by the non uniform beam profiles of the LEDs. This result corresponds to the simulation besides that the deviation is smaller than predicted.

The sensitivity is $E = U_{ps}/\Delta x = 1.51\ V/mm$. By adapting the gain of the photodiodes current to voltage converter or the gain of its high pass or the final low pass filter, the sensitivity can be increased.

4.2. Signal noise

The signal noise was measured with a high resolution digital multimeter in fast sample mode. The dominant frequencies were calculated by FFT (see fig.7.)

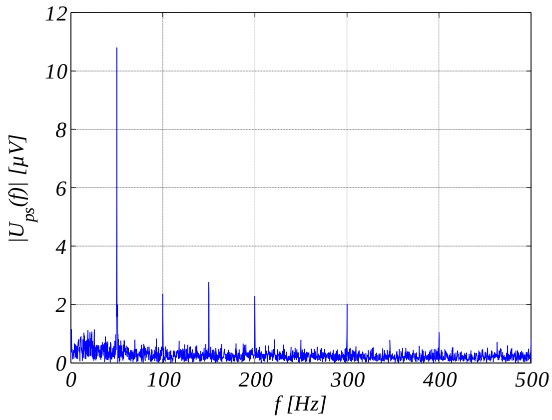

Fig.7. Signal noise of dual LED position sensor (FFT)

The most dominant disturbing frequency is at $f=50\ Hz$ and its multiples. These disturbing frequencies are caused by the power supply and can by suppressed by choosing an appropriate integration time of the multimeter.

5. CONCLUSIONS

A new method for an optical position sensor using two LED and a single photodiode including its electronics was described in this paper.

The dual LED position sensor uses simple optical components and relatively large aperture which can easily be manufactured. This is an advantageous setup compared to classical optical position sensors used in commercial EFC-balances using one LED, a differential photodiode and a narrow aperture because the differential photodiodes are relatively expensive and the manufacture of the narrow aperture is much more complicated.

The circuit for the dual LED position sensor generates modulated driver signals for the two LEDs and demodulates the received signal of the photodiode. Due to the modulation extraneous light does not influence the measurement.

The measured characteristic curve of the position sensor shows good linearity. The sensitivity of the position sensor can be increased by adapting the gain of the circuit. The signal to noise ratio of the received signal is good, disturbing frequencies are mainly caused by the power supply and can easily be suppressed by appropriate sampling strategies.

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