DESIGN AND IMPLEMENTATION OF AN INEXPENSIVE, HIGH RESOLUTION DISPLACEMENT AND VELOCITY SENSOR

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1. Introduction

For axial displacement and velocity measurements of a magnetic levitated rotor a sensor was needed with a relative position accuracy of under 5µm. Maximal propagation delay of the whole sensor system was specified with under 10 µs. The sensor system is placed near a strong magnetic field, therefore systems based on eddy-currents and hall-effect cannot be considered. Commercial displacement and velocity sensors that fulfil the technical requirements are too expensive. Based on the Photosensor EE-SX1070 from OMRON a displacement and velocity measurement system was developed which met the specific demand by negligible costs.

The simplicity of the system allows a broad field of application aside from rotating machines. The measuring range of the displacement sensor is 1 mm.

2. Operating Principle

The EE-SX1070 consists of an emitter, radiating light in the near infrared spectrum (940nm typical) and an optical transistor as detector (see Fig. 1). The transistor has a linear correlation between the detected light and the shaded sensor area. Only at the outermost regions a nonlinear characteristic occurs. The linear range is about ±0.5mm around the optical axis of the transistor.

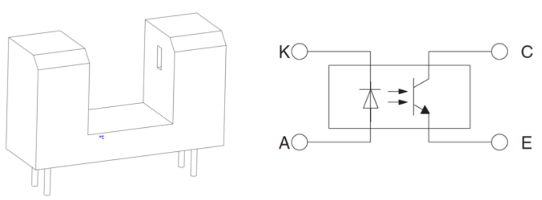

Fig. 1. Photomicrosensor EE-SX1070 [1].

For both, the displacement and velocity measurement the above mentioned transmissive sensor is used. Velocity signals are derived from the displacement values. Fig. 2 shows the arrangement of the displacement (red) and velocity (blue) sensors. The component being measured contains a panel that shades the optical transistor depending on the axial position of the component.

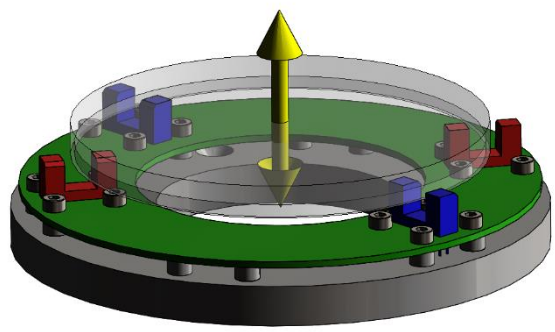

Fig. 2. Sensor configuration.

For error reduction the average of two individually evaluated sensors are used. Due to the separate treatment of the displacement and velocity sensors an error on the displacement signal caused by the differentiators can be excluded.

3. Signal Condition Electronics

The phototransistors are supplied with a constant voltage of 5 volts, therefore the current changes invers proportional to the immersion depth of the moving panel. This current signal is converted back to a voltage by leading it through a shunt resistor and amplifying it to meet the requirements of the following signal processing. A passive low-pass filter of first order with 100 kHz cutoff frequency suppresses high frequency interferences while creating negligible phase shift.

At this point the position signal is ready for further application specific processing (e.g. A/D conversion) or it can serve as a base for analog speed calculation.

To allow measurement of speeds in both directions while using single-supply components, the signal is superimposed with a DC bias voltage.

Due to the nature of the derivation it is essential to suppress high frequency signal noise. Therefore a chebyshev second order low pass filter is used [2]. The cutoff frequency should be adapted to match the highest possible speed of the mechanical system while phase shift has to be kept in an acceptable limit.

Afterwards the speed is calculated from the filtered signal by an enhanced analog differentiator circuit, that is optimized for stable behavior in the given frequency range [3]. The mechanical limitations of the speed serve as a base to set the time constant of the differentiator circuitry in order to avoid signal clipping and hence information loss.

To improve performance it is beneficial to use high oversampling rates when A/D converting the signals. In the given application a sampling rate of 1 MHz with an oversampling rate of 40 is used to achieve 25.000 measurements per second with an accuracy of less than 3.5µm for position and less than 3 mm/s for speed.

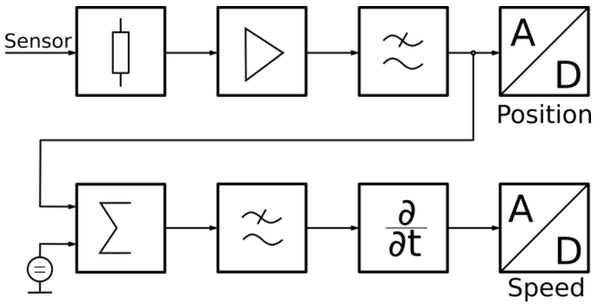

Fig. 3. Signal path.

4. System characteristics

4.1 Propagation Delay

The measuring distance for the displacement sensor includes the low pass filter and the wire between the sensor- and processing unit. In addition the velocity sensor includes the differentiator and the upstream filter. By bridging the diode supply a relative steep voltage drop can be produced (see Fig. 4 solid line). Both voltage curves were measured with a 12-bit digital oscilloscope. The propagation delay is around 5.4 µs for the velocity sensor and 3.2 µs for the displacement sensor due to the missing differentiator and low pass filter.

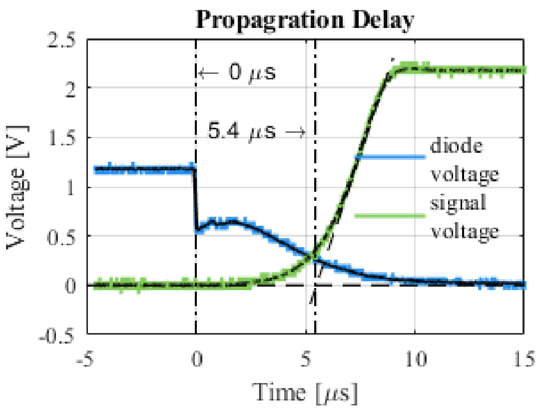

Fig. 4. Propagation delay of the velocity sensor.

4.2 Signal to Noise Ratio (SNR)

The dataset of the signal voltage provided by the propagation delay test (see Fig. 4) is also used to calculate the SNR.

$$\mathrm{SNR}=10*\log\left(\frac{u_{\mathrm{eff,Signal}}^2}{u_{\mathrm{eff,Noise}}^2}\right) \tag{1}$$

Based on Eq. (1) the SNR for the displacement and velocity sensors are listed in Table 1.

Table 1. SNR values.

	$u_{\mathrm{eff,Signal}}$ [V]	$u_{\mathrm{eff,Noise}}$[V]	SNR[dB]
Displacement	1.86	0.0062	49.5
Velocity	1.28	0.0334	31.67

5. Conclusions and Outlook

The sensor system presented in this paper provides a low cost alternative for contactless displacement and/or velocity measurements with a measuring range of 1mm. It was shown, that the required specifications were comprehensively fulfilled. With little effort, the circuit design can be adapted for different requirements.

By optimizing the electrical shielding and using high accuracy power supply sources the SNR should further increase with consistent propagation delay.

References

[1] Datasheet Photomicrosensor (Transmissive) EE-SX1070, *OMRON*

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