A positioning system using a contact-type capacitive displacement sensor

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Abstract

We developed a new 1-D positioning system in which a contact-type linear encoder-like capacitive displacement sensor (CLECDiS) was integrated as a displacement sensor. CLECDiS is a capacitive displacement sensor capable of providing high-resolution displacement information over a long range. A new supporting mechanism was developed and tested for integrating CLECDiS into a positioning system composed of dual actuators. In addition, conditioning circuits and a decoder was developed to enable CLECDiS to be used as a feedback sensor. The developed system is proven to have sub-100-nm resolution over a 10-mm displacement range.

1 Introduction

The contact-type linear encoder-like capacitive displacement sensor (CLECDiS) is an area-varying capacitive displacement sensor that uses periodic electrodes to obtain repeated signals over a long range, as a linear optical encoder does. Capacitive displacement sensors of this type are called comb-type sensors. CLECDiS has many small electrodes on both the stator and mover, and the gap between the facing electrodes contains two sliding thin dielectric films attached to the electrodes, as shown in Fig. 1. CLECDiS has been previously proven to provide displacement information in a sub-nanometer resolution over a centimeter range [1]. However, the implementation of CLECDiS into a conventional positioning system is extremely difficult because of sensitive contact conditions of the films on electrodes. In this study, we have developed a 1-D positioning system in which CLECDiS is integrated as a displacement sensor by devising a new supporting mechanism that keeps the contact condition stable between the coating layers of facing electrodes. In addition, we developed a signal conditioning circuit and a digital decoder for CLECDiS to achieve feedback motion control of the mover in the positioning system.

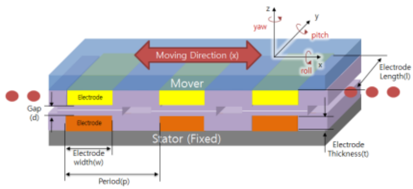

Fig. 1 Schematic diagram of CLECDiS

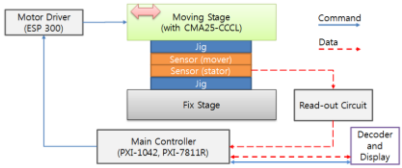

Fig. 2 Schematic diagram of the system

2 Positioning system

The developed positioning system is composed of a custom-made stage; CLECDiS; readout circuits including a preamplifier, signal conditioning circuit, and analog-to-digital (A/D) converters; and a main controller with the signal decoder, as shown in Fig. 2. The main controller can be used to translate the moving stage to a certain position and acquire the displacement data from CLECDiS through a decoding process inside the decoder.

CLECDiS was fabricated by micromachining. The fabrication process includes patterning a glass substrate by etching, depositing metal and silicon oxide layers, and then carrying out planarization by chemical mechanical polishing [2]. To obtain more stable signals with high S/N ratios, two CLECDiS sets (four electrode sets) are adopted. Each electrode is 50-μm wide, 13-mm long, and 200-nm thick (see Fig. 1). The dielectric (DLC) layer, which creates and maintains the gap between the facing electrodes, is about 230-nm thick; therefore, the gap becomes 460 nm.

The stage was designed such that the two CLECDiS sets could be installed stably and that the contact condition of the DLC layer could be controlled properly. The contact condition can be successfully stabilized by maintaining the ideal contact point at the fixed location in the moving electrode set during whole motion of the moving stage, as illustrated in Fig. 3. This operation can be achieved without controlling the rotation of the moving stage by releasing rotation of the sensor assembly relative to the stages. As can be seen in Fig. 3, the mover (of CLECDiS) should rotate as it translates over the surface of the stator because the surfaces of both the mover and stator are not perfectly flat. Therefore, the supporting structure for the sensor should be able to rotate about the pitching axis as freely as possible.

Capacitance variations are converted to electrical signals by using a custom-made circuitry based on a Low-Z amplifier ([3], 55p), and the output electrical signals are converted to the corresponding digital values using an A/D converter. The digital signals are then acquired by a field programmable gate array board with a differential operator, so that the two compensated digital signals could be obtained at the final stage for decoding. The decoder converts the compensated signals to the required displacement signals using the arctangent method [4].

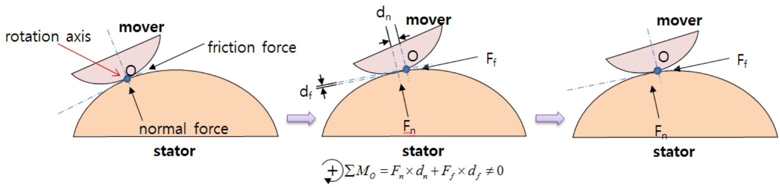

Fig. 3 Conceptual diagram of a contact mechanism

3 System testing

Experiments were performed to confirm whether the output signals could be stably obtained with high repeatability by verifying measured data deviation at identical positions during repeated movements of the stage. Such experiments are helpful for the performance evaluation of the CLECDiS-based displacement sensing system because the contact condition stabilizing mechanism as well as CLECDiS itself may considerably affect the output. The moving stage was made to translate at a constant velocity of 100 µm/s, so that one period output signal would be obtained in a second. The identical points used for verifying deviation are shown in Fig. 4(a) as a Lissajous graph. Each repeated implementation of the experiments consisted of a single forward movement and a single backward movement, and the alternating motions were repeated 10 times over a 3-mm range during the test. In each implementation, data for verifying deviation are acquired for positions from 1 to 30 (Fig. 4(a)); hence, 10 samples are used to determine the standard deviation and average at each position (total measured positions: 30). Then, at each measured point, the repeatability was estimated by calculating the “(max - min)/average” of the sensor’s measured output value. The system repeatability was same as the worst one, i.e., 0.79% (min: 0.47%, average: 0.66%).

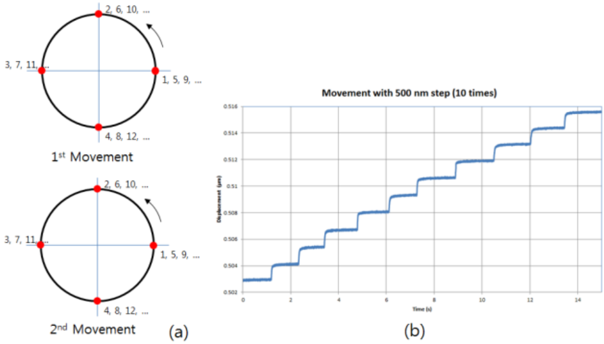

Fig. 4 Points for verifying repeatability (a) and measurement result (displacement) (b)

4 Results and conclusions

In this paper, we propose a new CLECDiS-based measurement system and confirm its repeatability. The repeatability was obtained by using the sensor's output deviation at specific positions and was found to be about 0.79%. The results indicated that the sensor's repeatability was sufficient for displacement estimation. Figure 4(b) shows a graph (for 10 500-nm step movements) of decoded displacement signals obtained from the developed system; the signals were found to be very stable. The current CLECDiS system has sub-100-nm resolution over a 10-mm displacement range, and further studies will be conducted to make it more precise and stable.

Acknowledgment

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