LINEAR AND ANGULAR MEASUREMENTS

EXPERIMENTAL STUDY ON A PLANAR CAPACITATIVE DISPLACEMENT SENSOR

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An experimental study is described on a planar capacitative displacement sensor. It differs from existing models in being simple and giving scope for using film techniques. The sensor is particularly effective in measuring large displacements, e.g., in physics equipment.

A capacitative linear-displacement sensor can be based on the principle that the through capacitance alters between two immobile electrodes when a third screening electrode moves between them. This principle has been implemented in a precision probe [1] and also in an instrument for recording the linear displacements of a piston [2]. These sensors contain a system of three coaxial cylinders whose assembly represents major difficulties, particularly in devices intended to measure large displacements.

Here we present results on a capacitative sensor employing a similar principle but simpler in design, and which in particular allows one to use film techniques.

Figure 1 shows the design. The sensor consists of two packets of glass plates 1, on the planes of which are deposited the electrodes 7, together with the two bases 4 and 5 containing slots, in which the screen electrode 6 moves. Its displacement is limited by the stop 3. Between stop 3 and screen electrode 6 there may be end measures 2, which are used to calibrate the sensor. The total length of a packet of glass plates is 200 mm. In the initial state, the screen is inserted in the slots in the bases up to the stop, which lies at 15 mm from the end of the packet. The thickness of the glass plates is \( h = 5 \) mm, width \( b = 10 \) mm, and gap between electrodes \( d = 1 \) mm, and with the screen in that position the through capacitance is 0.95 pF. With the screen fully inserted, the through capacitance is increased to 11.13 pF.

The current value of the through capacitance is measured precisely by three-terminal connection to the circuit shown in Fig. 2. We used MGTFE-0.25 screen conductors 1.5 m long, with the screens in the conductors joined to the mobile electrode and the jacket of the converter. The circuit included a standard R589 transformer bridge, which provided a resolution of \( \pm 0.001 \) pF in the range from 0 to 10 pF.

The noise level is a major characteristic that governs the resolving power. The noise in the measurement channel is made up of the fluctuations in the measurement circuit containing the coupling lines and the inherent noise of the sensor. The noise level of the R589 digital bridge with the above coupling lines is not more than \( \pm 0.001 \) pF. When the sensor is connected, the noise level increases because of fluctuations in through capacitance arising from changes in humidity, temperature, air pressure, and transverse displacements of the screen due to mechanical noise and so on. With the screen completely withdrawn, the noise band does not exceed \( \pm 0.002 \) pF with a standard deviation of 0.0002 pF. This very low noise level is provided by the use of a three-terminal connection, which virtually eliminates effects from the parasitic impedances of the working electrodes with respect to ground. An additional measure that reduces the effects of variations in through capacitance between the electrodes is that the working electrodes are placed on individual glass insulators. This design has an advantage over locating the working electrodes on a common insulator with guide slot between them because only an air gap appears between the working electrodes.

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Fig. 1. Capacitance sensor design: 1) glass plate packets; 2) end length measures; 3) stop; 4 and 5) bases with slots; 6) screen electrode; 7) electrodes; $h$ and $b$ respectively the thickness and width of a packet, $d$ gap between two packets, i.e., between immobile electrodes.

Fig. 2. Connection of sensor to measuring circuit: 1) fixed electrodes; 2) mobile screen electrode; 3, 4, and 5) sensor connection terminals; 6) measurement circuit; $d$ and $a$ gap between fixed electrodes and length of them.

This also explains the low temperature dependence of the through capacitance, which does not exceed 0.002 pF for 10°C (on prolonged heating in the range up to +50°C). When the mobile electrode is inserted in the guide slots, the noise level increases because the transverse slack in the screen is not less than 0.3 mm. The maximum noise level occurs with the mobile electrode completely inserted. In that case, the noise excursions attain ±0.01 pF.

We prepared a set of end measures having nominal lengths of 10, 20, 40, and 80 mm to calibrate the sensor and examine the transformation equation. Combinations of these enable one to set any displacement of the mobile electrode in the range from 0 to 160 mm with a step of 10 mm and a relative error of not more than 0.05%. The calibration was performed as follows. The set of measures corresponding to a given point in the range was placed on the upper end of the sensor as shown in Fig. 1. Then the mobile electrode was inserted into the gap up to the stop provided by the set of measures, after which the through capacitance was measured. The calibration cycle included successive setting of displacements from 0 to 160 mm with a step of 10 mm by that method. The data from three calibration cycles were processed by least squares. With a gap between the working electrodes of 1.1 ± 0.1 mm, linear approximation gives the conversion equation

\[
\tilde{C}_x = 0.58 + 0.42x.
\]

The actual conversion equation is nonlinear, with the nonlinearity estimated as ±0.7%. The more exact conversion equation is

\[
\tilde{C}_x = 0.5 + 0.4x - 0.005x^2 + 0.00002x^3.
\]

The fitting error is random and is governed by the accuracy of the end measures. The nonlinearity is due to various factors, of which the most important are:

1. Lack of parallelism (taper) in the gap between the working electrodes along the sensor;