MEASUREMENT OF SMALL LINEAR DISPLACEMENTS WITH INDUCTIVE TRANSDUCER

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Abstract*:* This article discusses inductive transducers and their application for linear displacement measurement. The functions of conversion are experimentally defined and examined.

Key words: Linear displacement, nonelectrical measurement, inductive transducer,oscillator, frequency discriminator, Wheatstone Bridge.

1. Electromagnetic induction principles

Michael Faraday was one of the first scientists to study the relationship between magnetism and electricity. Faraday's Laws can be summarized as:

The magnitude of an EMF produced in a conductor is proportional to the rate of change of magnetic flux-linkage experienced by the conductor. When a conductor is exposed to a changing magnetic field, an electric current will flow in the conductor.

The EMF given by the rate of change of the magnetic flux is:

$$e = -\frac{d\Phi_B}{dt} \qquad (1)$$

where e is the electromotive force (EMF) in volts and Φ_B is the magnetic flux in Webers. The direction of the electromotive force is given by Lenz's law.

For a tightly wound coil of wire, composed of N identical loops, each with the same Φ_B, Faraday's law of induction states that

$$e = -N\frac{d\Phi_B}{dt} \qquad (2)$$

where N is the number of turns of wire and Φ_B is the magnetic flux in Webers through a *single* loop.

We can vary the induced emf by varying N or $\frac{d\Phi_B}{dt}$. Changing N is hard to do because it is a physical dimensional change. It is easier to change e by changing $\frac{d\Phi_B}{dt}$.

2. Self inductance

A single coil of many turns has inductive properties due to the magnetic interaction of adjacent loops in the coil. If the loops are wound in the same direction the total effect of this interaction is an induced back emf that opposes the initial current change. This self inductance is a form of inertia resisting current change in the coil. The self- induced emf E can be expressed in equation form as follows:

$$e = -L\frac{di}{dt} \qquad (3)$$

where L is the self-inductance and Δi/Δt is the current change per unit time in the coil. If E is measured in volts and Δi/Δt in amperes per second, the inductance is given in henries, 1 H = 1 V-sec/A. The negative sign is consistent with Lenz's law and conservation of energy.

Thus we have an expression for the coil inductance.

$$L = \frac{N^2}{S} \quad \text{or} \quad L = N^2 m_0 m_r \frac{a}{i} \qquad (4)$$

where $S = \frac{i}{m_0 m_r a}$ - reluctence.

From the formula it is seen that the inductance can be varied by varying the parameters N, m_r, a or i.

3. Mutual inductance

When an emf is induced into a circuit by a change of flux that is produced by a current changing in an adjacent circuit, the property is called mutual inductance (M).

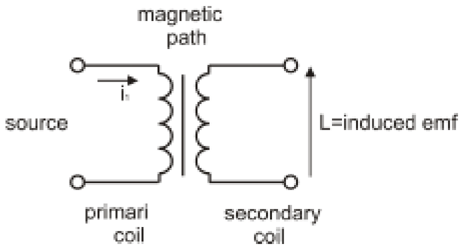

Fig.1. Mutual inductance curcuit

On fig. 1 an AC source generates an alternating current in the primary coil. This produces an alternating flux in the magnetic path which induces an alternating emf in the secondary coil. If the secondary circuit were closed, an alternating current would flow in it. This is the principle of the transformer.

The induced emf is the secondary circuit is given by:

$$e_2 = \frac{N_1 N_2}{S}\frac{di}{dt} \qquad (5)$$

where N_1 and N_2- number of turns on primary and secondary coils.

If we replace $i = i_{\max}\sin wt$ in the above expression, we can deduce the transformer equation for secondary emf.

$$E_2 = 4{,}44 f N_2 \Phi_{\max}$$

4. Measurements of variations in the value of inductance

One method of detecting a change in the value of inductance is to use a Wheatstone Bridge circuit at AC (fig.2).

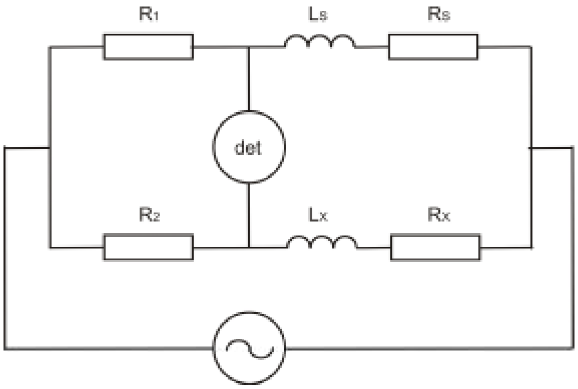

Fig.2. Wheatstone Bridge circuit

When the circuit is balanced we have the following equations:

$$R_x = \frac{R_s R_2}{R_1} \qquad (6)$$

$$L_x = \frac{L_s R_2}{R_1} \qquad (7)$$

Standard inductors are not easy to manufacture, so this method is very seldom used. It also suffers from the usual disadvantages of bridge measurements.

5. Block diagram of an inductive transducers research for measurement of small linear displacements.

On figure 3 is shown the block diagram of an inductive transducer for measurement of small linear displacements.

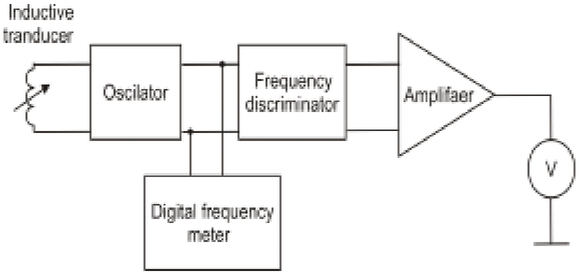

Fig.3. Block diagram

Fig.4 shows the scheme for research on the transformation functions. The way it works is: the inductance varies the frequency of an oscillator, whose output is passed through a frequency discriminator to a detector.

The inductive transducer becomes part of the tuned circuit of the oscillator, and varying the inductance by varying the position of the transducer will vary the frequency of oscillation.

The frequency discriminator contains a circuit for converting these variations into voltage variations. These voltage variations are then amplified and indicated on the meter.

An inductive transducer can be used with an oscillator, a frequency discriminator and an amplifier to form a complete FM system. Movement of the inductive transducer varies the frequency of the oscillator and this frequency change is accompanied by a change in output from the discriminator, which can be measured and related to the transducer position.

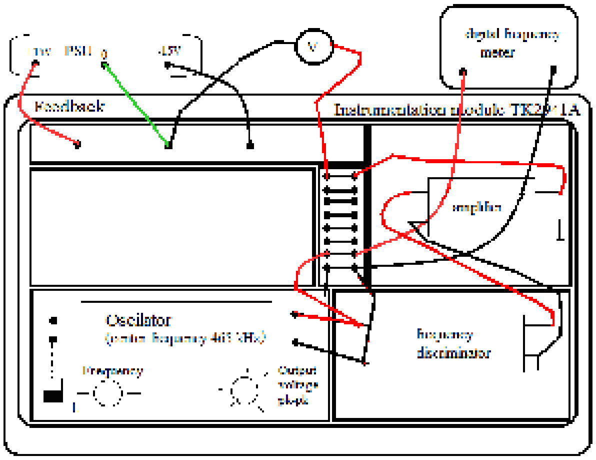

Fig.4. Scheme for research on the transformation functions

Fig. 5 shows connect the experimental set.

Fig. 5. Experimental set

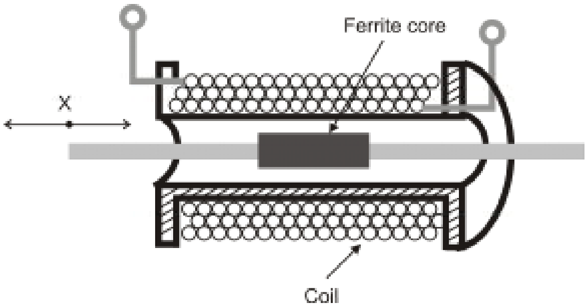

Fig.6. Single-coil variable inductance transducer

Fig. 6 shows single-coil variable inductance transducer for linear displacements. It consists of a single coil wound around an insulating former. Into it can slide a core of a ferrite material with a relative permeability m_r. The value of m_r is given by the slope of B/H curve of the ferrite material. Since the value of H changes as we push the core into the coil, so the value of m_r may change if the B/H curve is not linear. The core is attached to a rod which fits on to the slider of TK294, enabling the position of the core inside the coil to be measured.

6. Measurement results

Examining the transformation functions of the inductive transducers for measurement of small linear displacements.

The measurements were made under the following conditions: frequency of the measured signal 476 kHz, the operational amplifier gain is set to 10, linear displacement from 0 to 22 mm.

6.1. Examining the transformation function of a single inductive transducer with a moveable core for the presence of hysteresis.

The transducer is examined on a position of the slide at 55 mm and a change of the linear displacement from 0 to 22 mm and from 22 to 0 mm.

The results are shown on figure 7 and in table 1. On figure 7 it is obvious that almost a linear transformation function can be achieved for linear displacements from 3 to 9 mm and almost the same values for both directions.

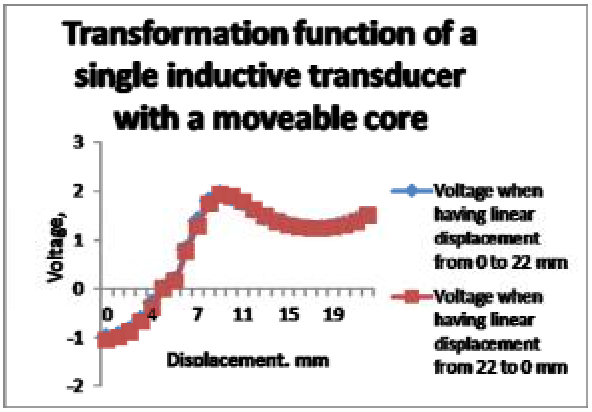

Fig.7.

6.2. Examining the transformation function of a single inductive transducer with a moveable core when the position of the slide is changed to 50 mm.

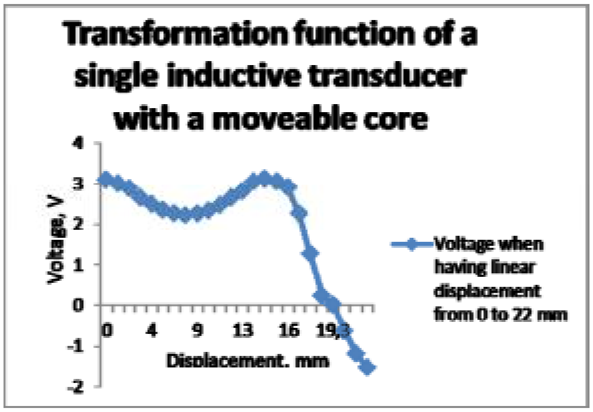

Fig.8.

The results are shown on figure 8 and in table 2. On figure 8 it is obvious that almost a linear transformation function can be achieved for linear displacements from 16 to 22 mm and almost the same values for both directions.

Table 1

Linear displacement	**Voltage when having linear displacement from 0 to 22 mm**	**Voltage when having linear displacement from 22 to 0 mm**	**Absolute error**	**Relative error**
[mm]	[V]	[V]	[V]	%
0	-1	-1,05	0,05	5,00
1	-0,96	-0,99	0,03	3,13
2	-0,84	-0,88	0,04	4,76
3	-0,63	-0,67	0,06	6,35
4	-0,28	-0,38	0,1	3,57
4,65	0	0	0	0
5	0,17	0,16	0,01	5,88
6	0,8	0,76	0,04	5,00
7	1,4	1,29	0,11	7,86
8	1,81	1,75	0,06	3,31
9	1,94	1,93	0,01	0,52
10	1,89	1,91	0,02	1,06
11	1,76	1,79	0,03	1,70
12	1,61	1,64	0,03	1,86
13	1,48	1,5	0,02	1,35
14	1,38	1,39	0,01	0,72
15	1,31	1,31	0	0,00
16	1,26	1,27	0,01	0,79
17	1,24	1,24	0	0,00
18	1,24	1,24	0	0,00
19	1,27	1,27	0	0,00
20	1,32	1,31	0,01	0,76
21	1,41	1,39	0,02	1,42
22	1,52	1,52	0	0,00

Table 2

Linear displacement	Voltage when having linear displacement from 0 to 22 mm
[mm]	[V]
0	3,1
1	3,01
2	2,89
3	2,65
4	2,5
5	2,35
6	2,26
7	2,22
9	2,26
10	2,34
11	2,48
12	2,65
13	2,82
14	3,05
15	3,11
15,5	3,06
16	2,9
17	2,26
18	1,27
19	0,24
19,3	0
20	-0,63
21	-1,19
22	-1,53

7. Conclusion.

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The paper is dedicated on the inductive transducers and their application for measurement of small linear displacements in the order of mm. Experimentally are defined and examined the transformation functions of the inductive transducer and it is defined the linear part of the transmission characteristic. The transducers are connected in a circuit consisting of resonant circuit, oscillator, discriminator, amplifier and a voltmeter. These transducers can be applied very successfully where it is needed a precise determination of the location of objects in the order of µm and mm. It can be used to design a meter movement device but just for very little movements where the transformation function is linear.

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